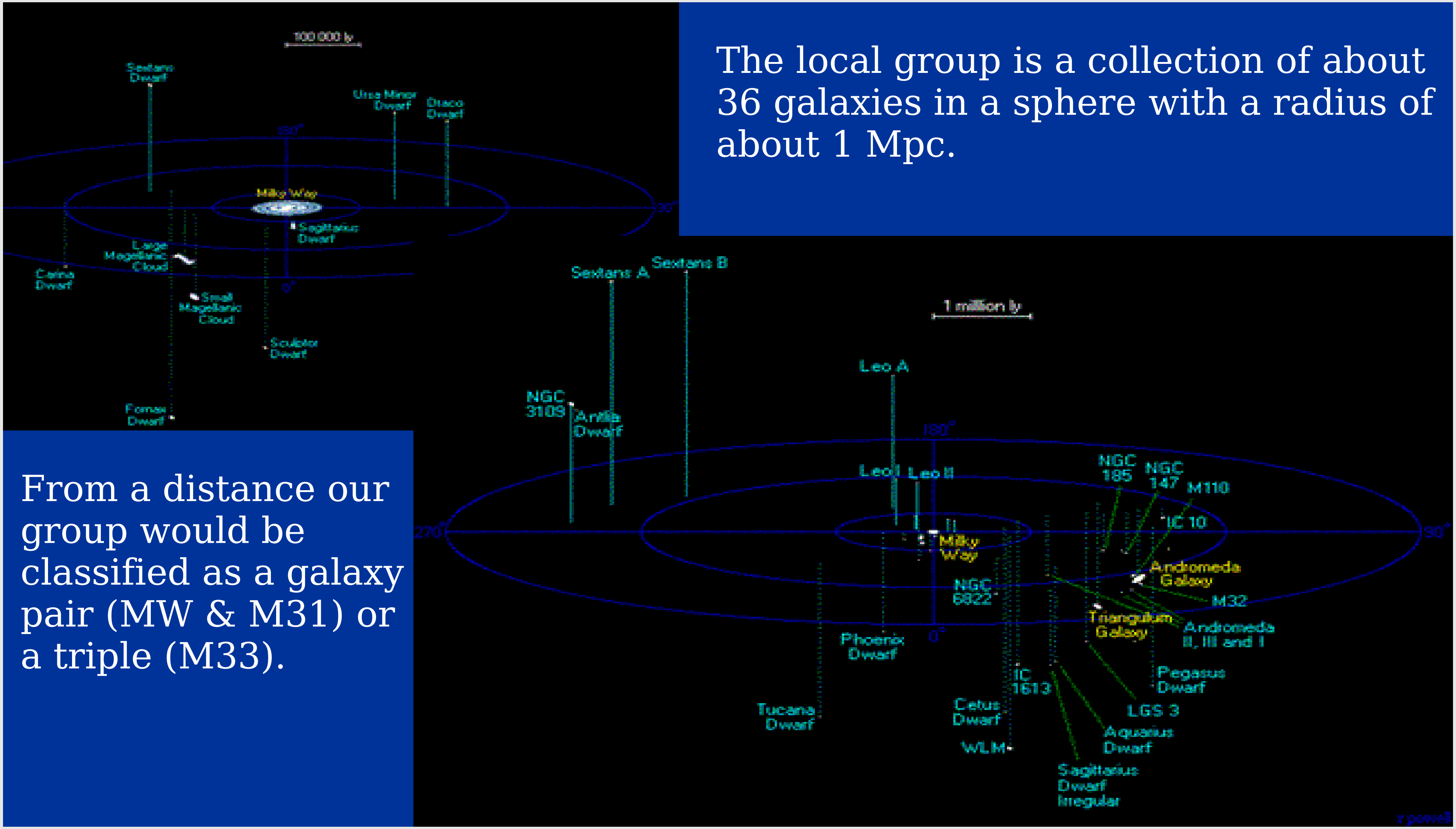
Local Group

1st test is March 15

Beyond our Galaxy: The local group



The local group is a collection of about 36 galaxies in a sphere with a radius of about 1 Mpc.

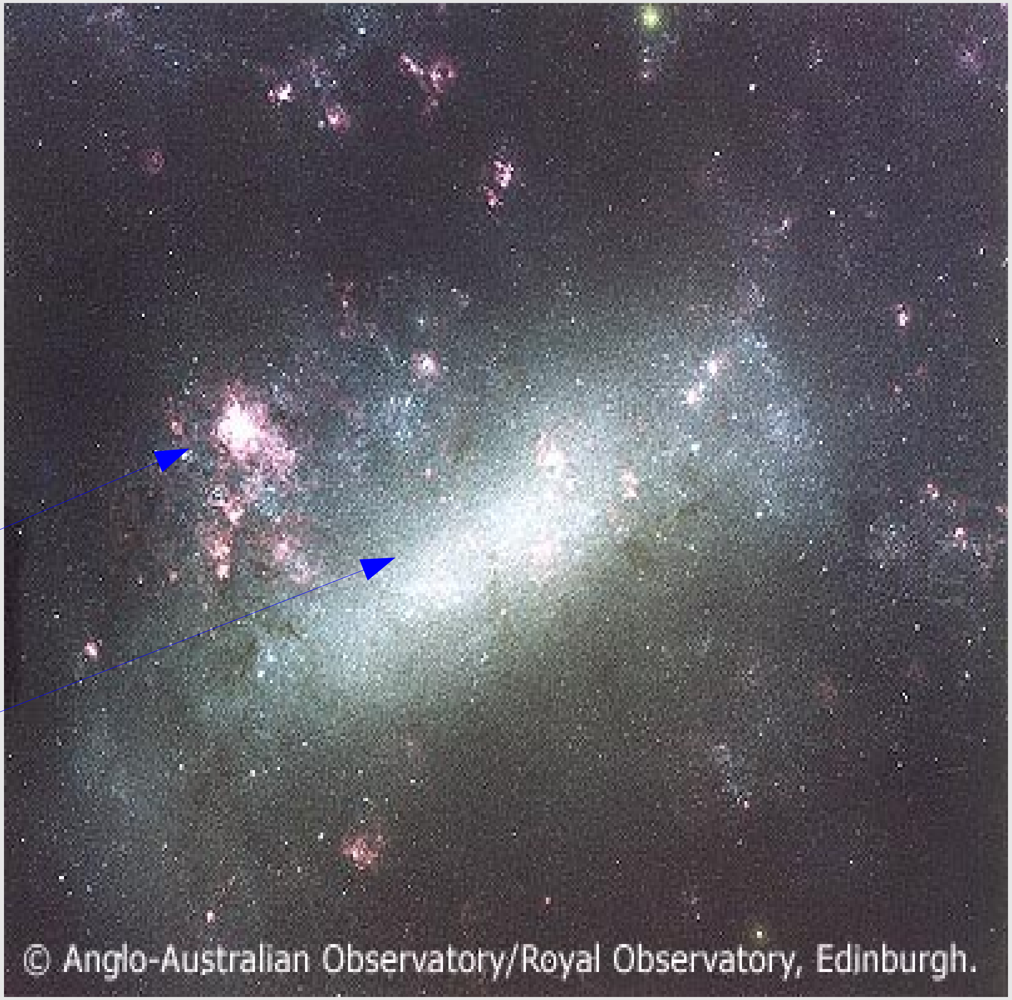
From a distance our group would be classified as a galaxy pair (MW & M31) or a triple (M33).

Most prominent satellites of our Milkyway are the Magellanic Clouds.

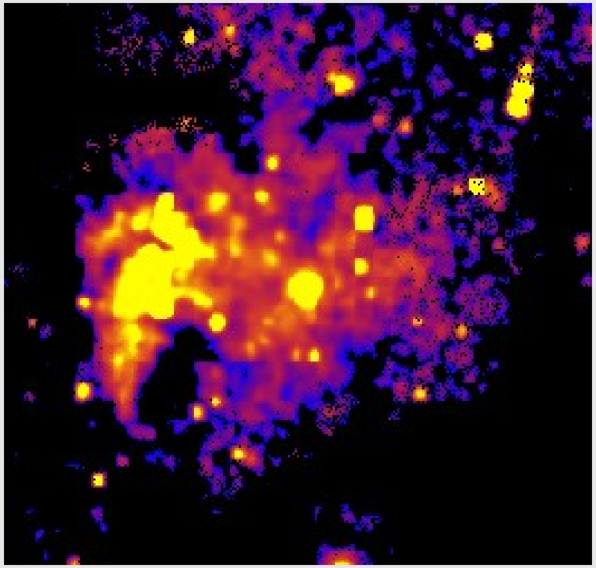
Image credit: Bill Keel

The LMC

- Distance 50kpc
- Dwarf Irregular
  - Type Sm
- Tarantula Nebula
  - active star forming region
- Barred galaxy
- $L \approx 1.7 \times 10^9\ L_\odot$

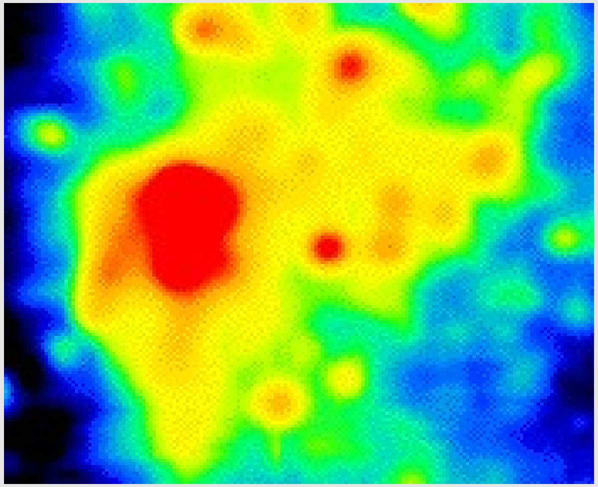


Xray: ROSAT



AAO optical 3 color

IRAS (Jason Surace)

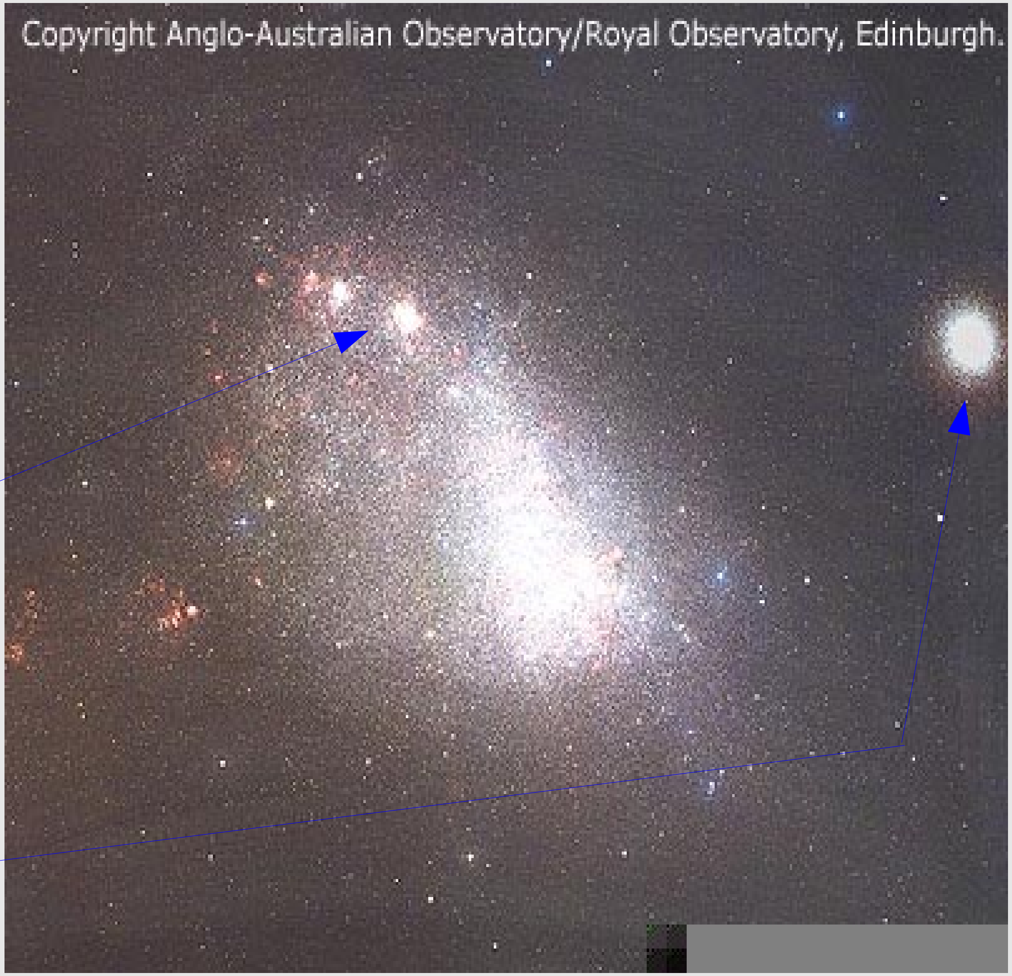


Radio (RAIUB/MPIFR Bonn

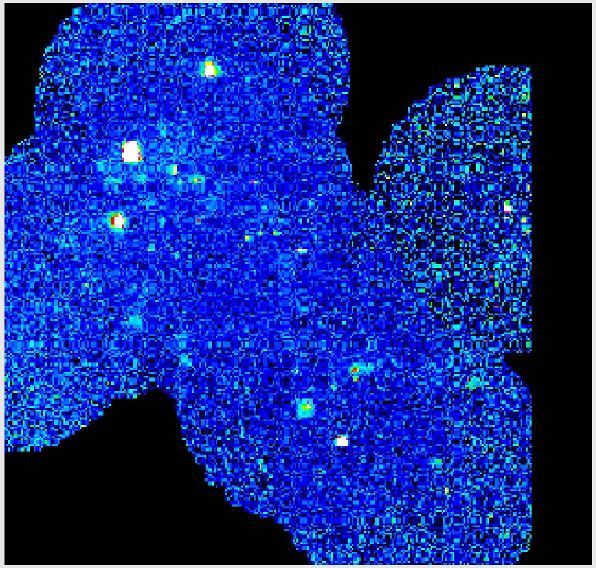
Each image is about 4°.5 on a side (9x moon's diameter)

The SMC

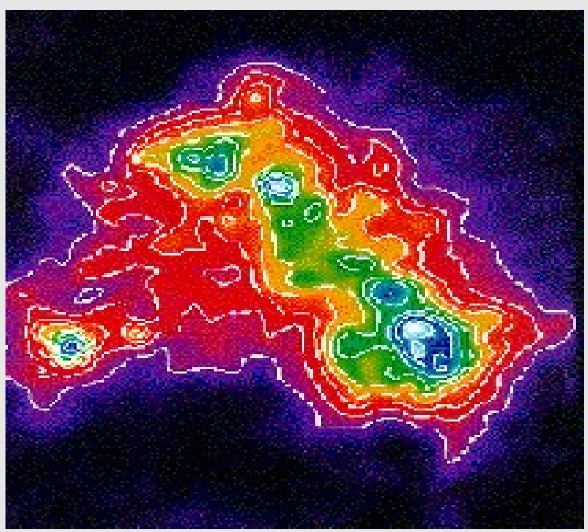
- Distance 58 kpc
- Dwarf Irregular
  - Type Irr
- NGC1978
  - Active star forming region
- $L \approx 3.4 \times 10^{8}\ L_{\odot}$
- 47 Tucanae
  - MW Globular Cl



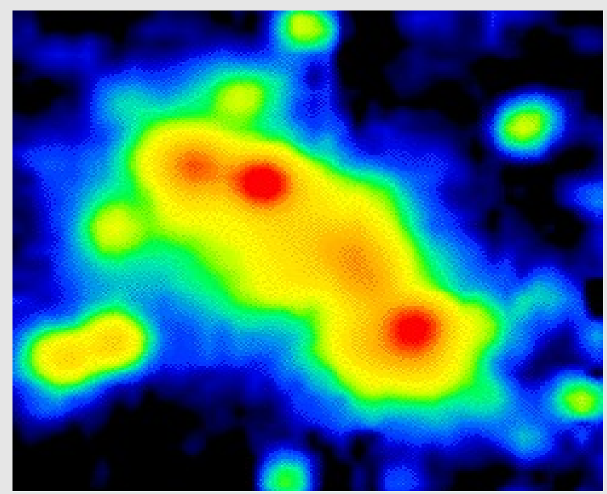
Xray: ROSAT



AAO optical 3 color



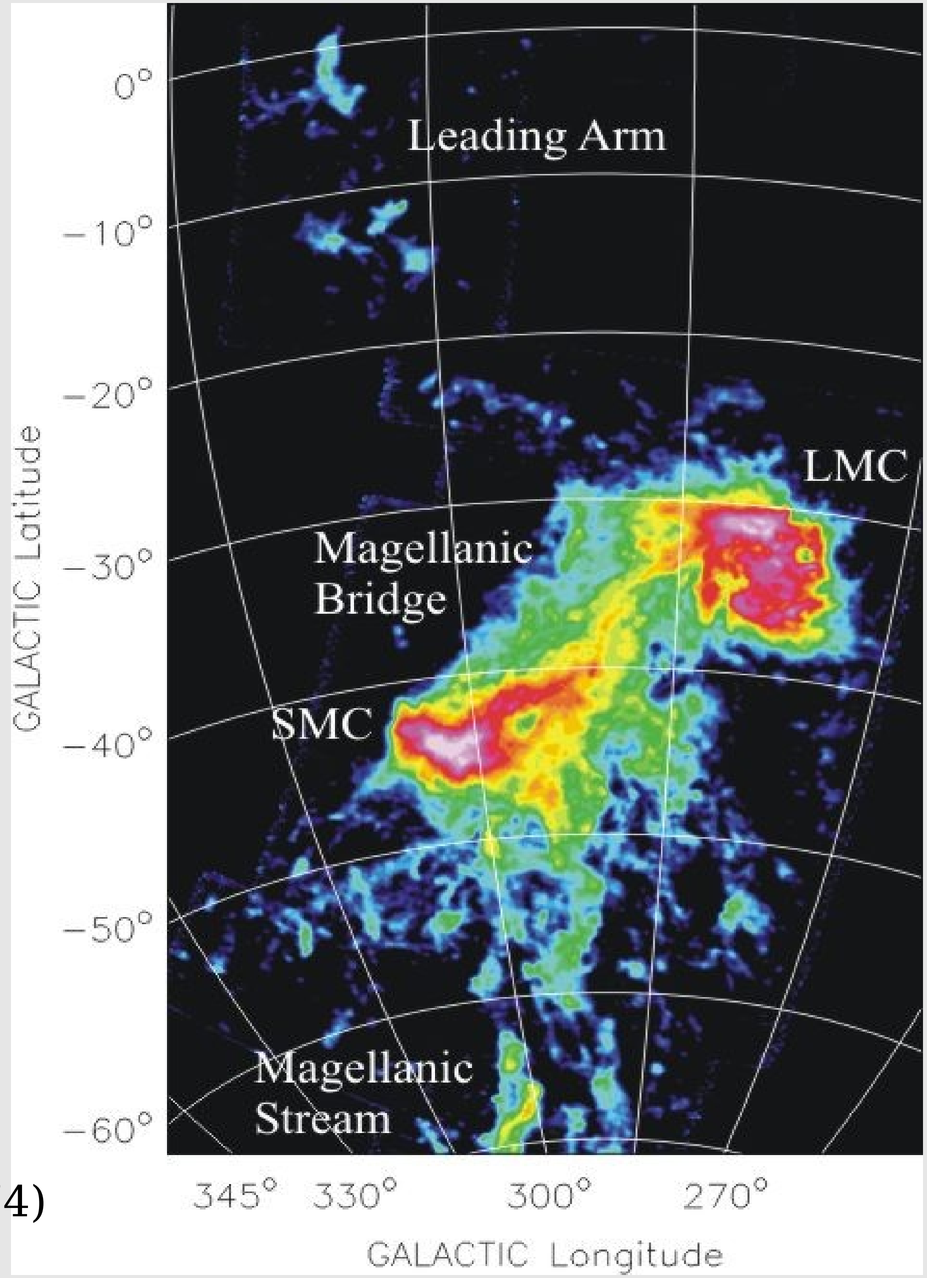
IRAS



Radio (RAIUB/MPIFR Bonn)

Each image is about 4°.5 on a side (9x moon's diameter)

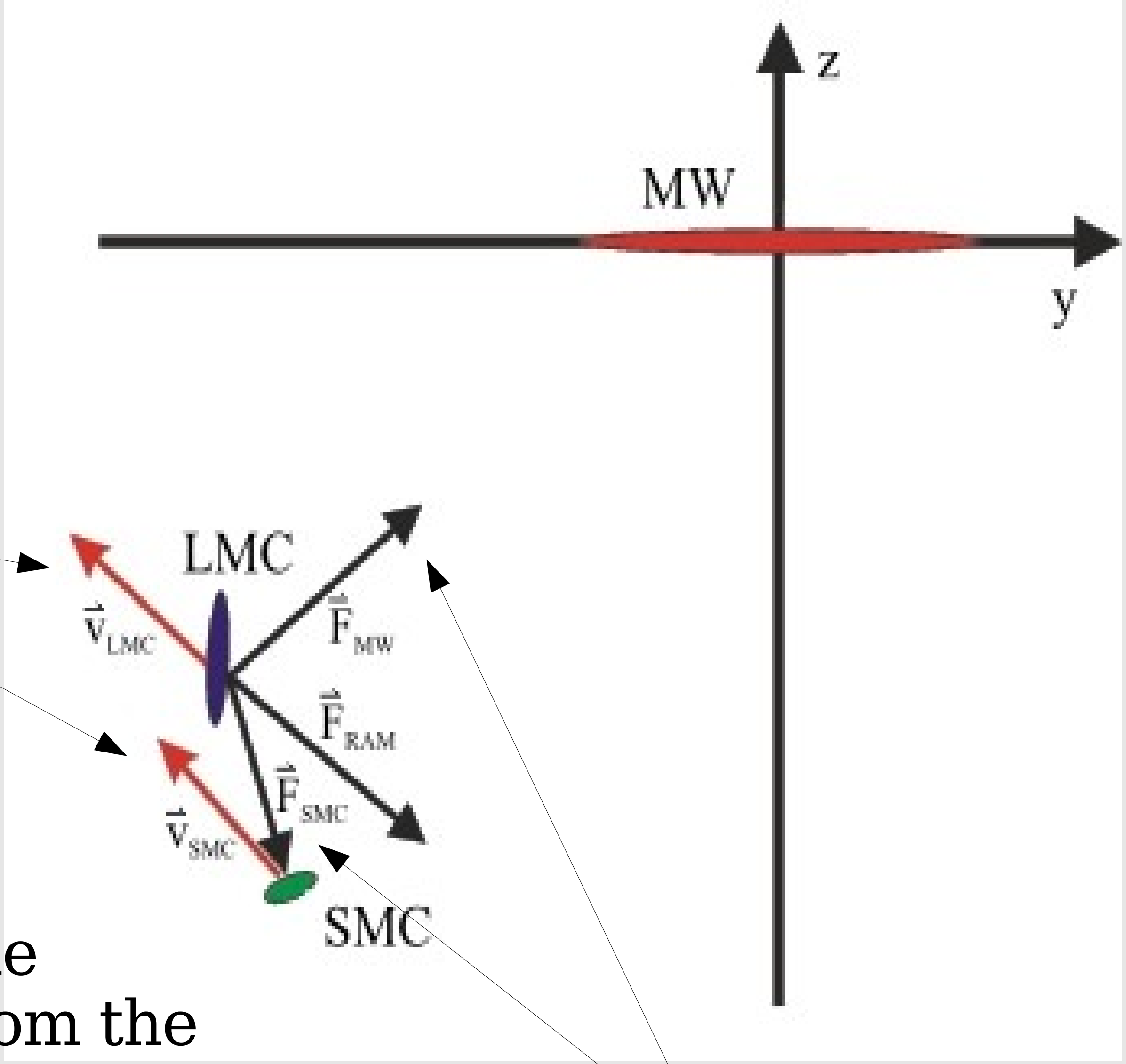
- Clues to the MC's dynamics
  - Common HI envelope
  - Stream of gas “following” the MC's



Magellanic Bridge (Hindman 1961)
Magellanic Stream (Mathewson et al. 1974)
Leading Arm (Putman et al. 1998)

(RAIUB/MPIFR Bonn)Brüns et al 2004 A&A

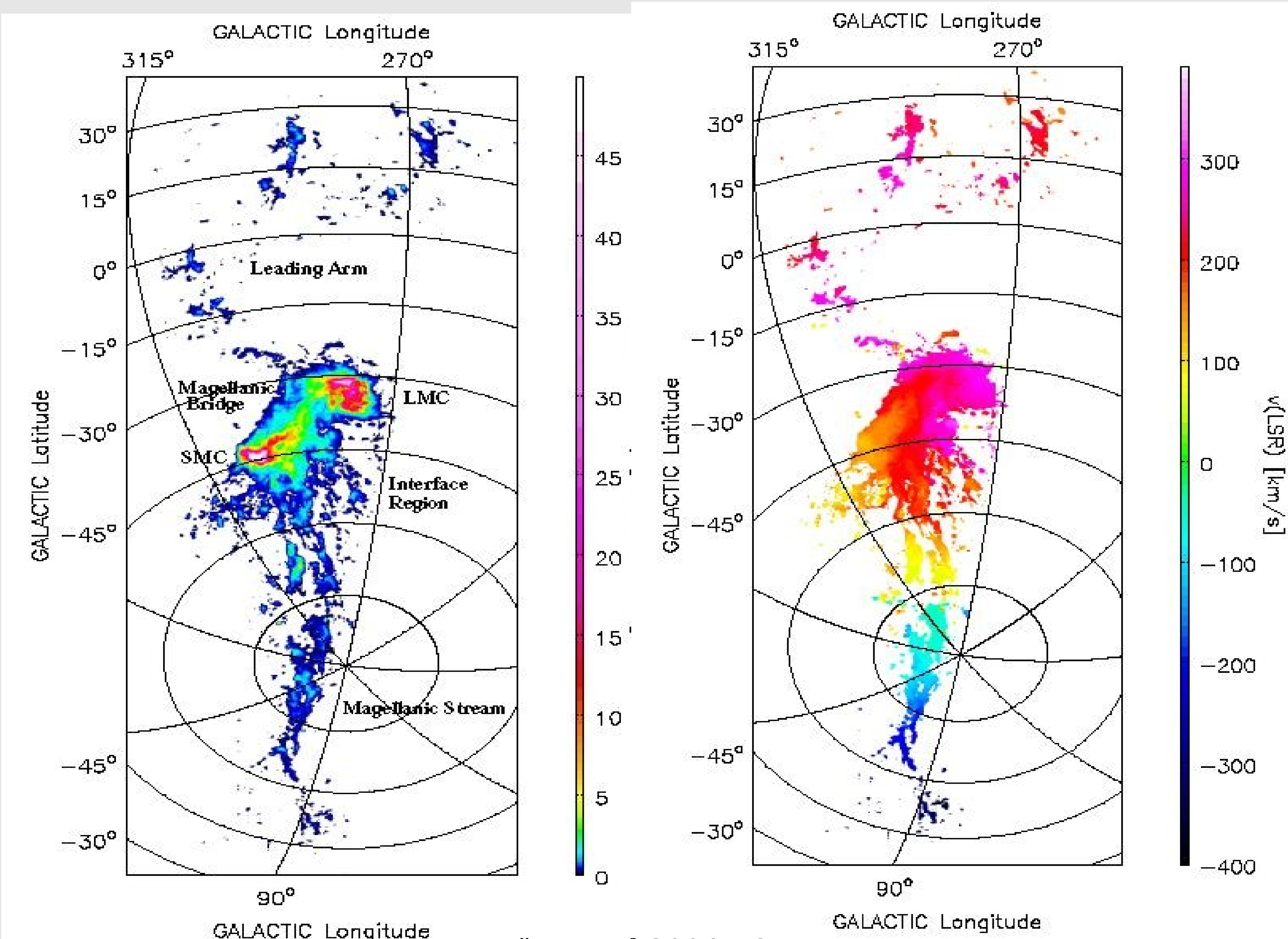
Forces on the Magellanic Clouds



Space Velocity

Ram Pressure is the force on the gas from the gaseous halo of the MW.

Gravitational Force



Brüns et al 2004 A&A

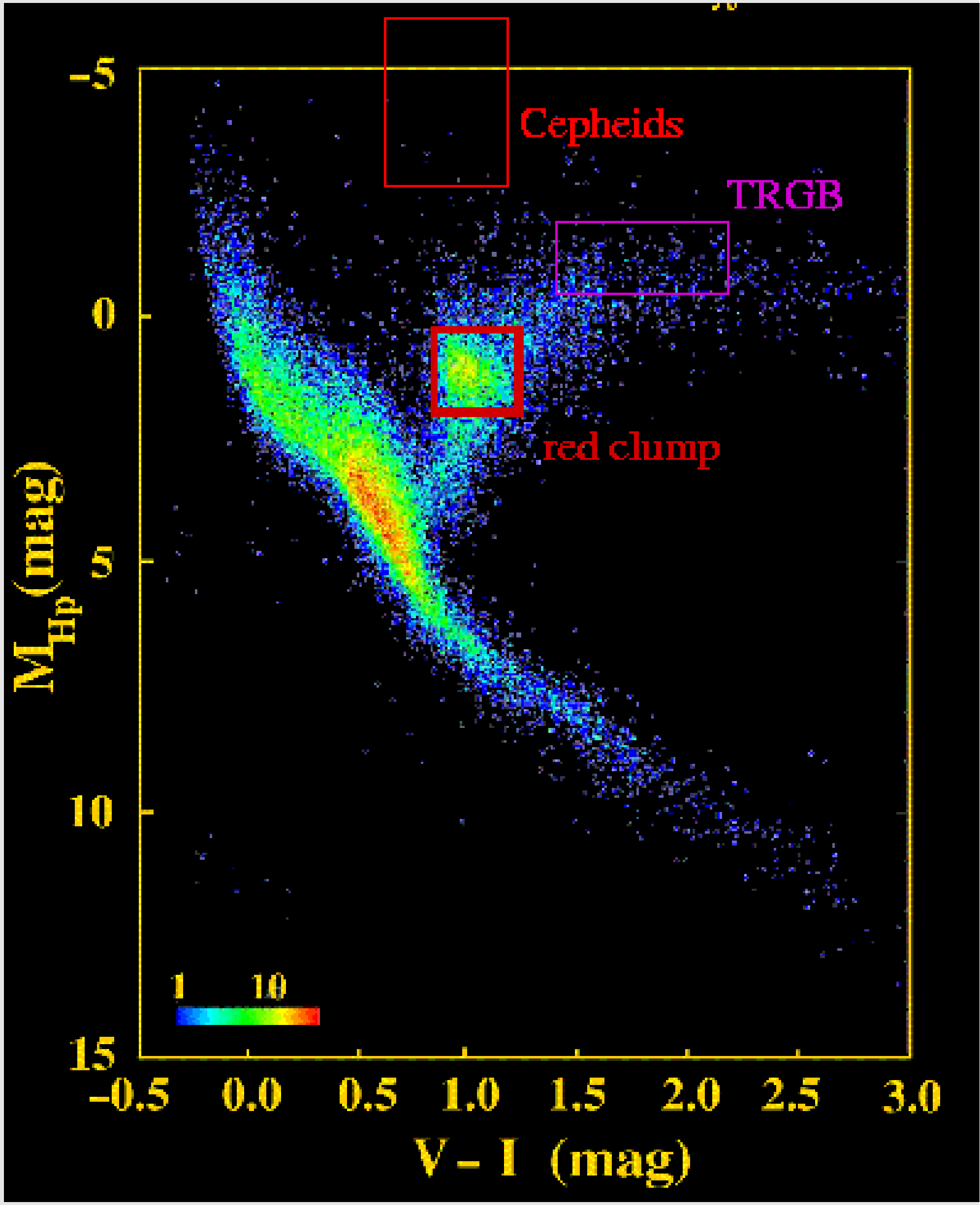
To accurately determine the orbit for the MC's we need the position (x,y,x) and the velocity v_x,v_y,v_z. We can measure the position and the *radial* velocity very accurately but determining the tangent velocity for objects at the distance of the MC's is very uncertain.

v_x, v_y, v_z [km/s] 41±44, -200±31, 169±37
Kroupa & Bastian (1997)

v_x, v_y, v_z [km/s] -56±39, -219±23, 186±35
van der Marel et al. (2002)

We also need the distance to the LMC

- Distance Indicators
  - Cepheid Variables
    - Very accurate
    - Very rare
  - RR Lyrae variables
    - Only one close Enough to be Measured accurately



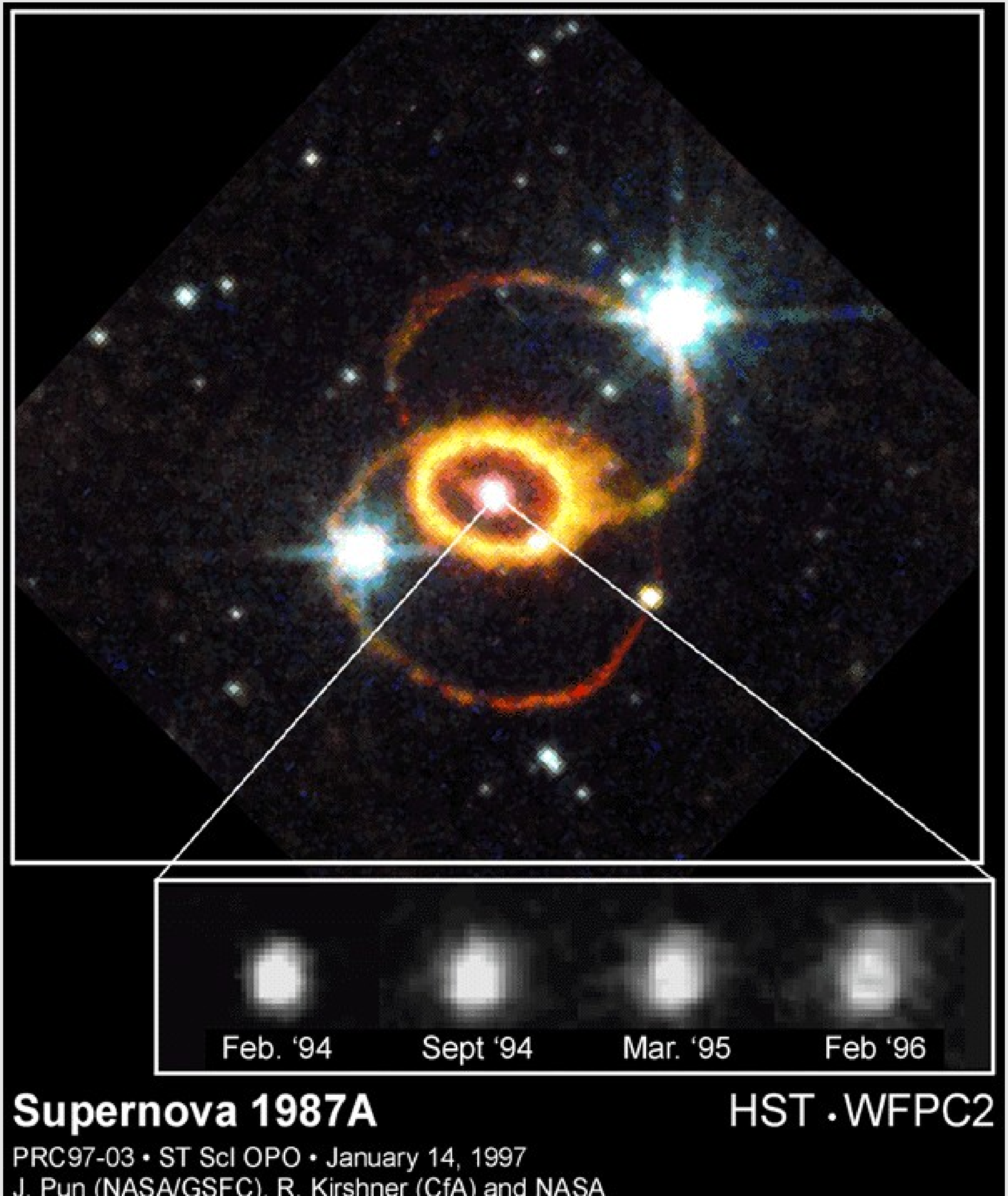
- Main Sequence Fitting
  - Compares HR diagram for stars in clusters – can get accurate relative distances
    - Problem – the LMC has a different chemical composition than the MW so we have to also apply a theory to do the comparison
- Tip of the Red Giant Branch
  - Many of these type stars are close enough for Hipparcos to measure their distance in our Galaxy and get absolute magnitudes.
    - Problem – Chemical composition again

- The Red Clump
  - Stars burning He -> Carbon tend to lie in one area of the HR diagram
    - Problem – astronomers cannot agree if all red clump stars are the same or do their properties vary from galaxy to galaxy
- Supernova 1987a

Supernova 1987A

Hubble Heritage

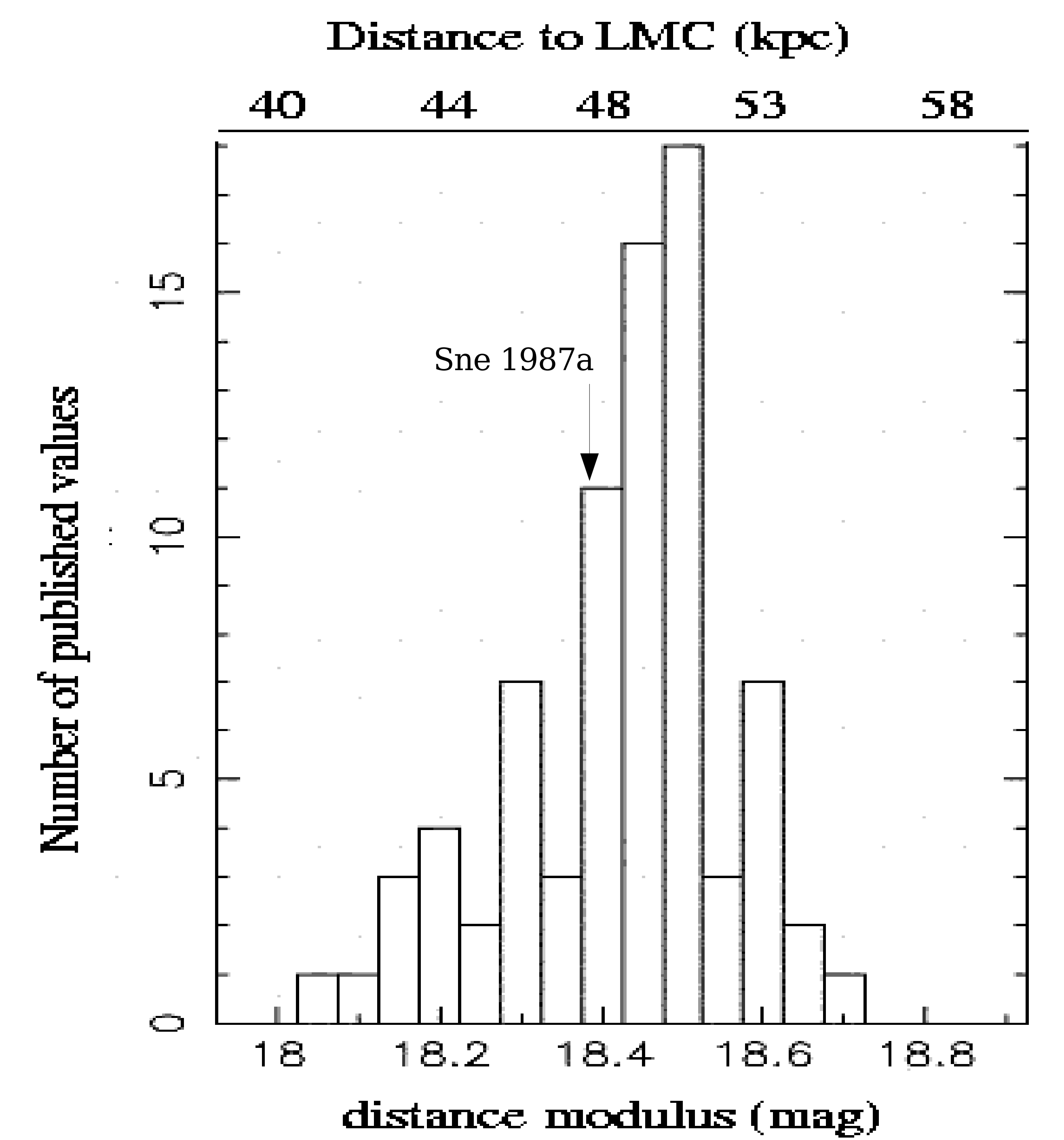
PRC99-04 • Space Telescope Science Institute • Hubble Heritage Team (AURA/STScI/NASA)



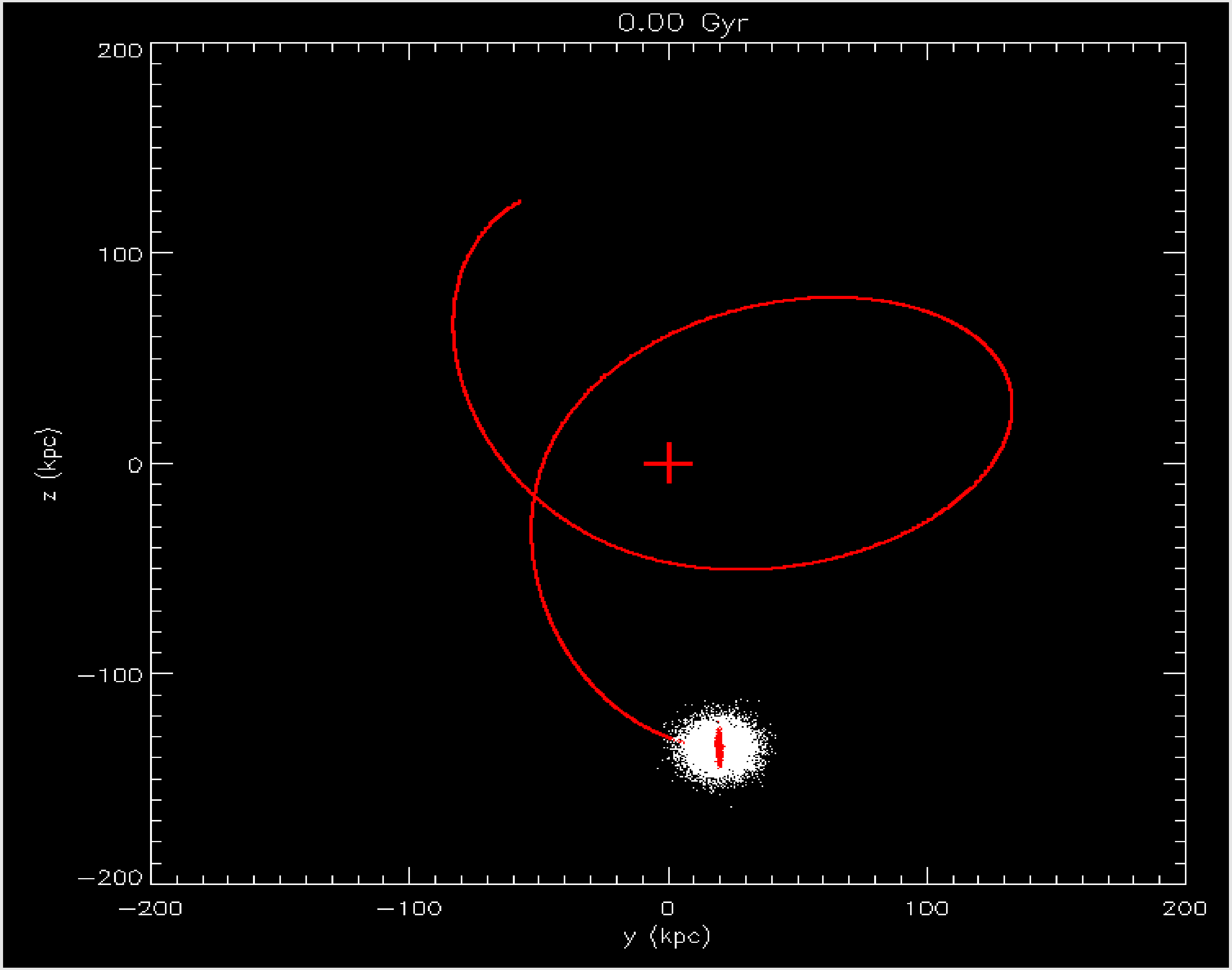
We know when then Sne exploded and when the rings lit up from the explosion. Thus the distance is d = t/c. We can measure the spectrum of the rings and derive a velocity and if they were ejected from the star the two distance measurements match. So we think we know the absolute size of the rings and thus the distance to the Sne and the LMC!

Distance Measurements to the LMC

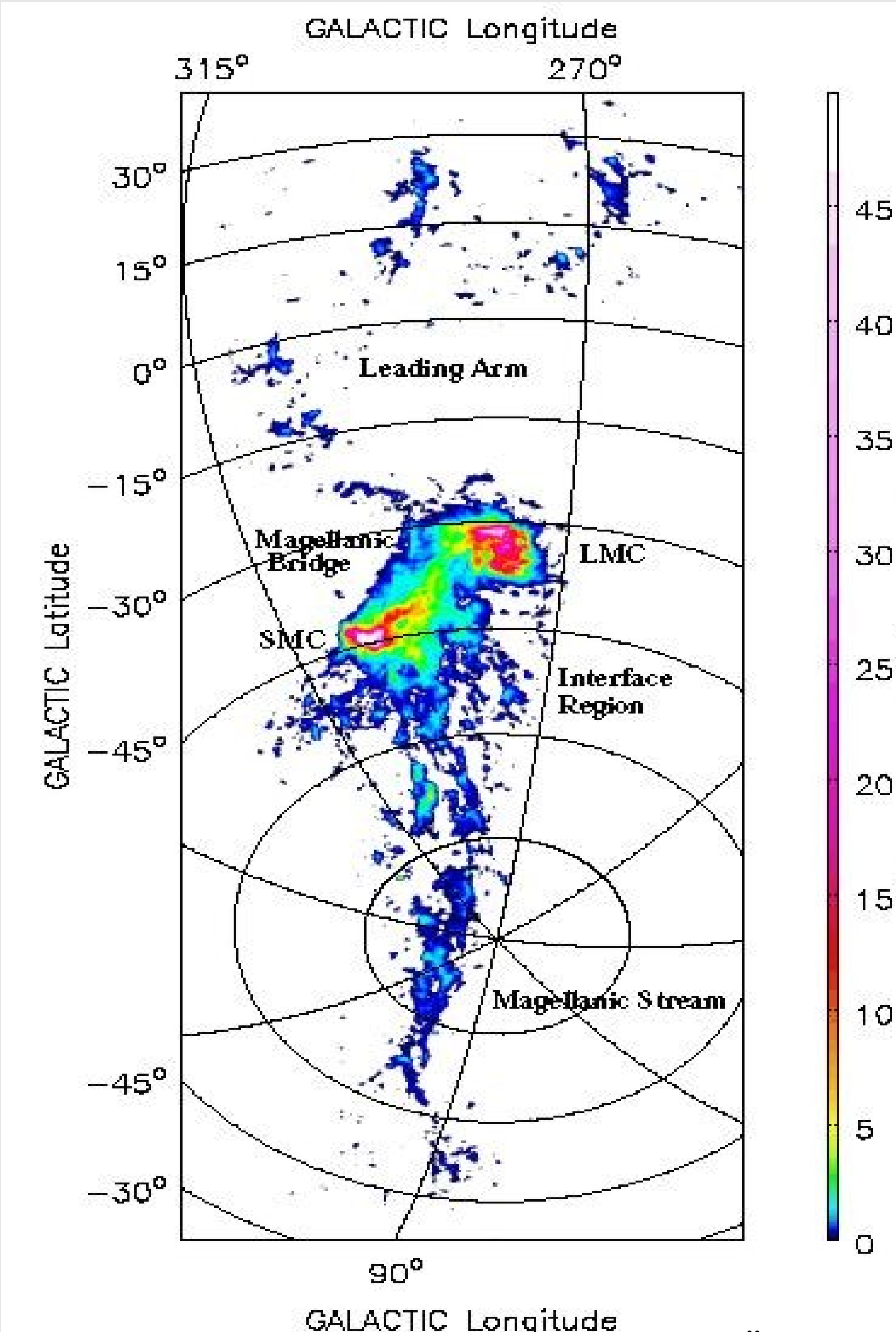
Method	LMC Distance (kpc)		
RR Lyrae	45 +/- 7		
	46 +/- 4		
	51 +/- 10	Kovacs (2000)	
MS Fitting	52 +/- 3		
Binaries	48 +/- 3	Nelson et al. (2000)	Same system
	44 +/- 6	Udalski et al. (1998)	VV2274
	41 +/- 13		
TRGB	52 +/- 5		
	51 +/- 6	Cioni et al. (2000)	
Red Clump	44 +/- 6		
	52 +/- 5		
Mira type	50 +/- 9		
SN 1987a	52 +/- 4		
	47 +/- 2		

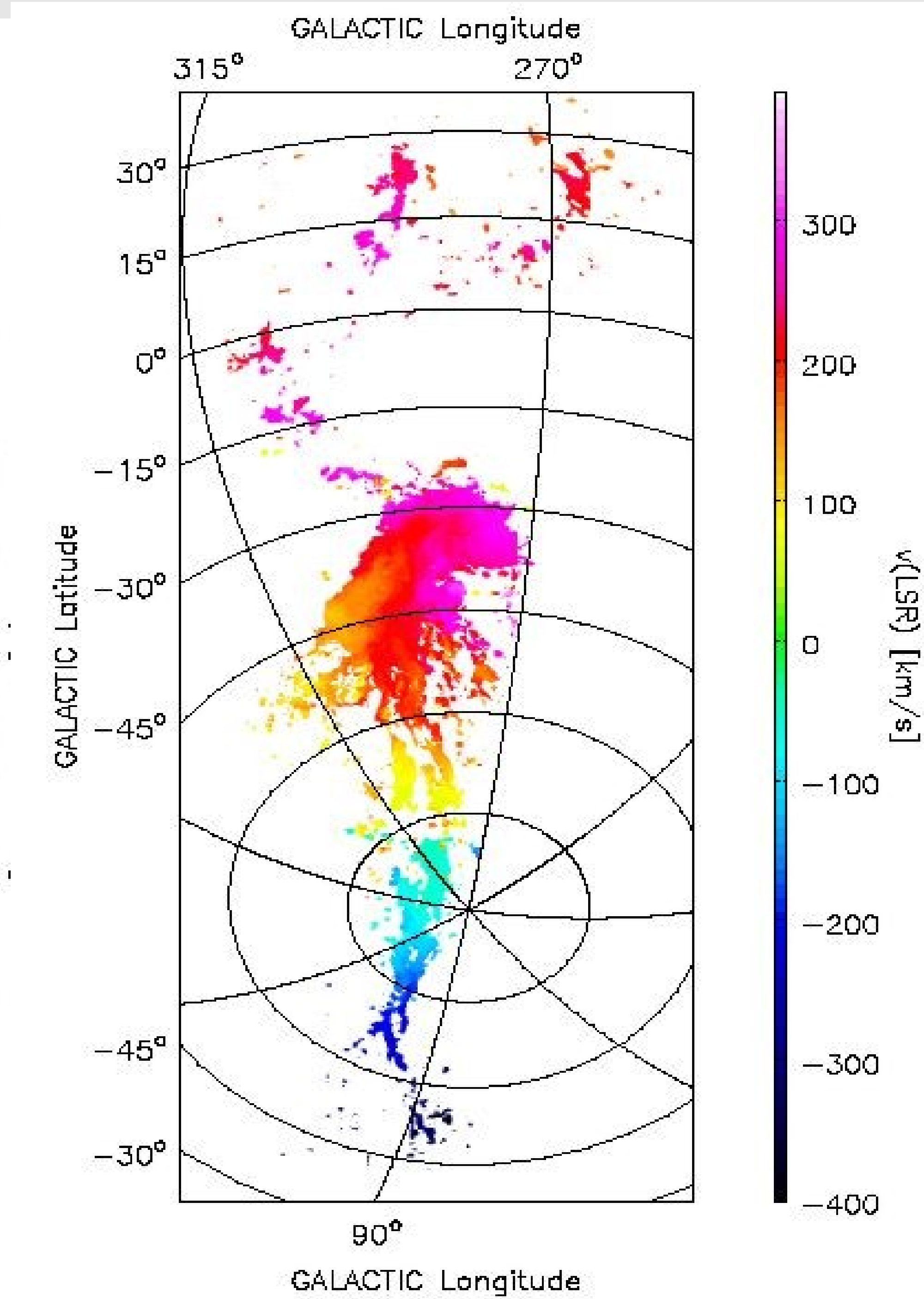

Distance to LMC (kpc)
40
44
48
53
58
Number of published values
0
5
10
15
Sne 1987a
18
18.2
18.4
18.6
18.8
distance modulus (mag)

So now we have all the information we need to model the system and find out the fate of the Magellanic Clouds. The simulation consists of 65k masses. Now the luminosity of the LMC is $L \approx 1.7 x 10^9 \ L_\odot$ so if each star in the LMC was like the sun there would 10^9 stars. So each mass in the simulation represents $\approx 10^4 M_\odot$.



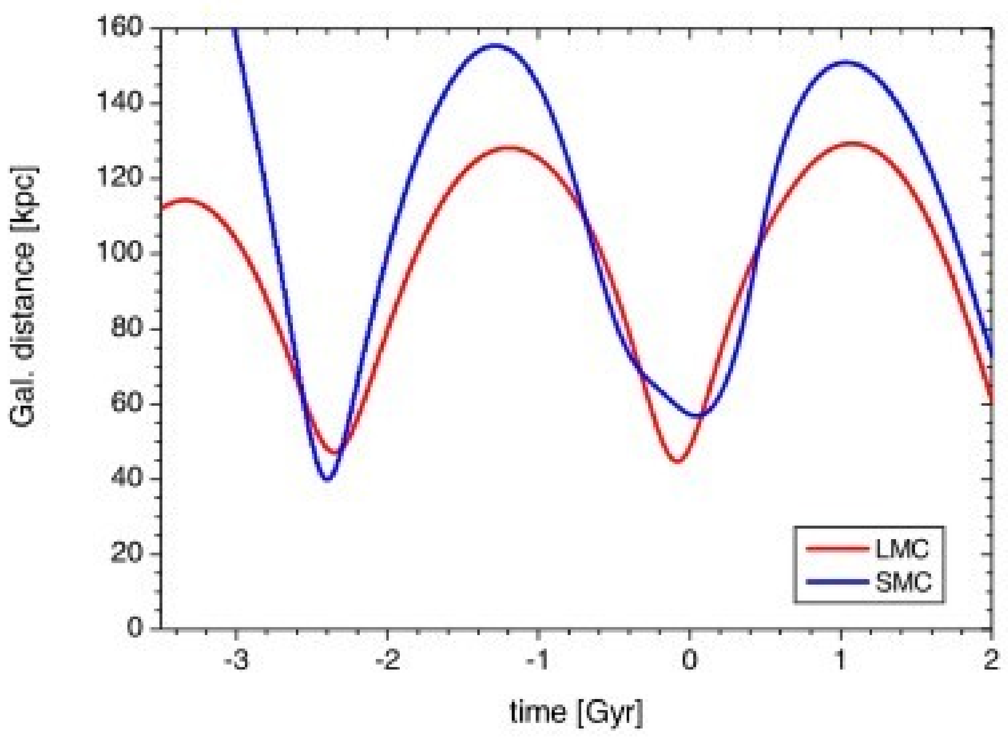
Simulation from R.C. Brüns University of Bonn

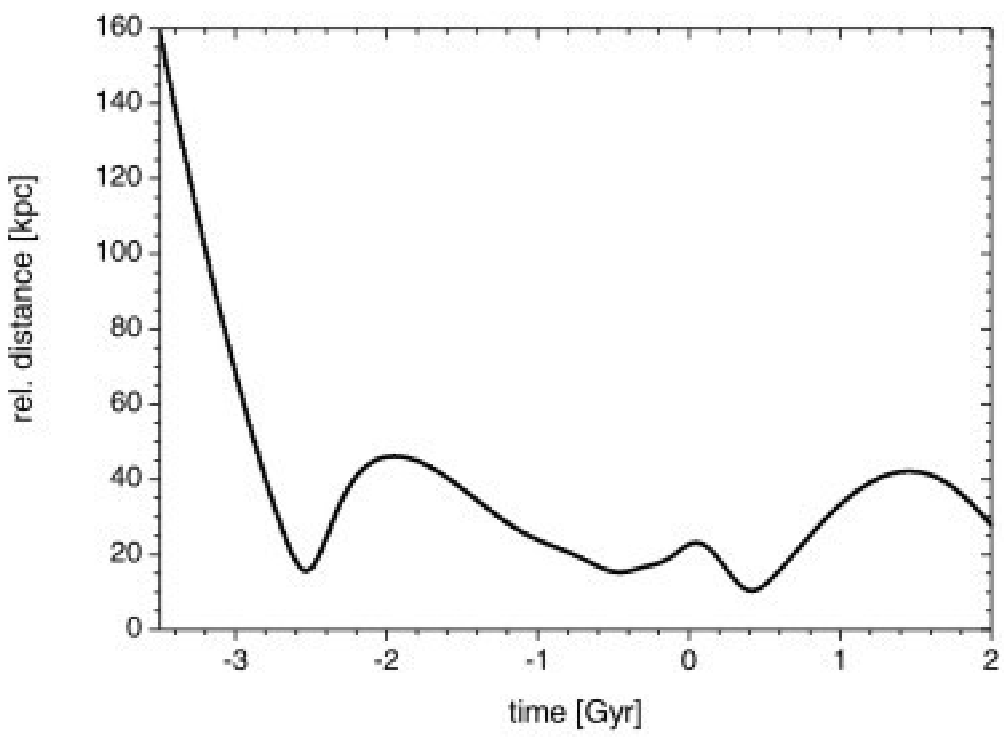


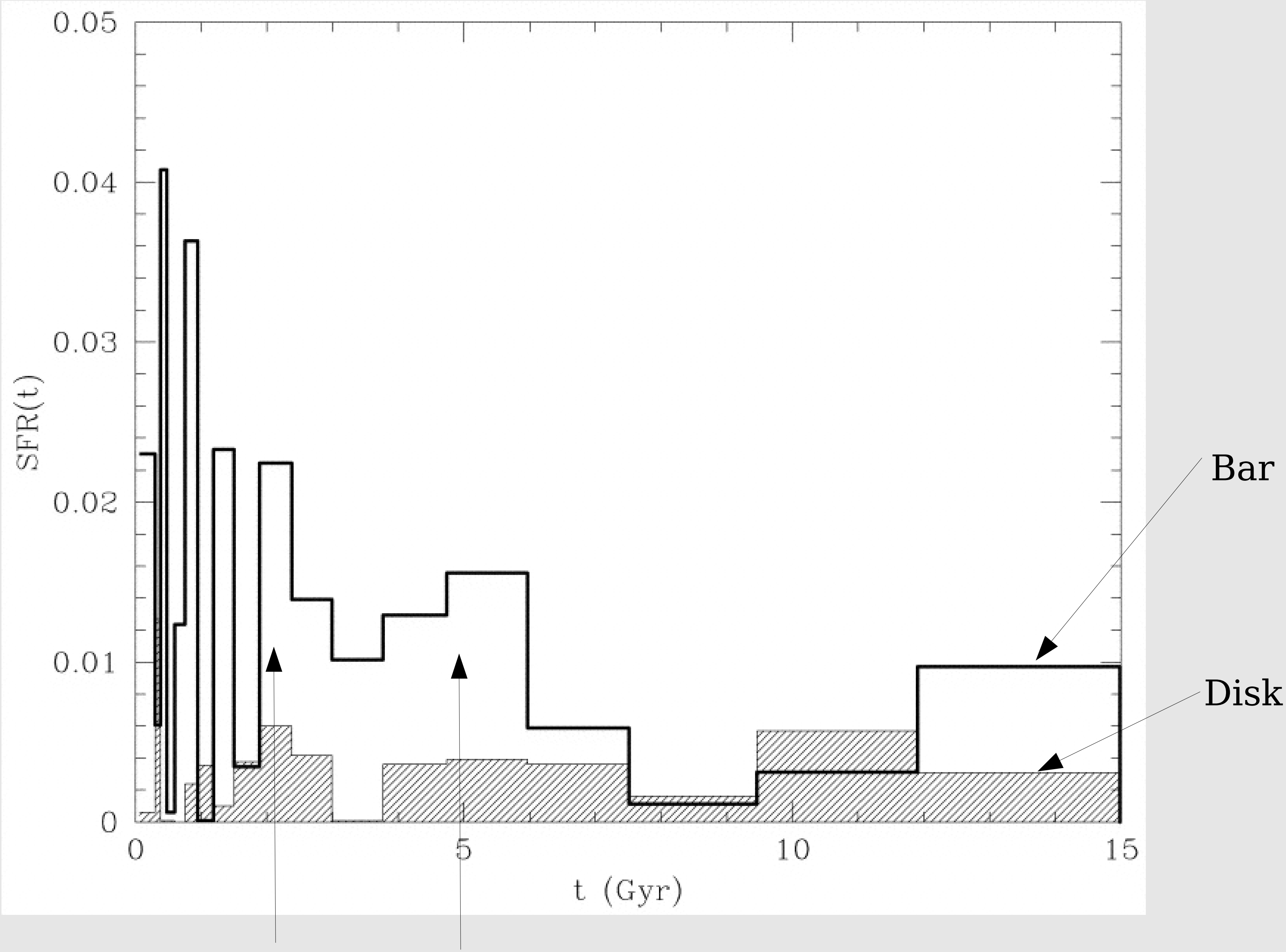


Brüns et al 2004 A&A

In addition to the orbiting the MW the LMC and SMC also orbit each other. On the left you can see that the MC's orbit the Galaxy with distances between ~40 kpc and 150kpc over a 2.5 Gyr period. The two clouds have several close encounters (~15 kpc) but do not merge over the simulation time.







Bar shows two episodes of star formation at 4-6 Gyr
and at 1-2 Gyr (Smecker-Hane 2002).

Questions Local Group galaxies can answer

- Is there relationship between dwarf irregular (dIrr) and dwarf spheroidal/dwarf elliptical (dSph/dE) galaxies? The Local Group contains low-luminosity galaxies of both types and this provides some ways to address this question (e.g. Bothun et al 1986, Binggeli 1994, Skillman & Bender 1995).
- Low-luminosity dwarfs tend to be metal poor; thus, the low luminosity dwarfs in the Local Group represent a sample of galaxies that is still largely composed of nearly primordial material.

- They play an important role in addressing the DM problem, allowing us to map the distribution of DM and placing constraints on the nature of the DM. In fact, dwarf galaxies are amount the “darkest” galaxies known.
- There is ample evidence that interactions play an important roll in the evolution of of these systems e.g. The LMC and SMC.
- The large luminosity range of Local Group dwarfs makes them excellent labs to study how other fundamental parameters vary with luminosity, such as DM content, the interstellar medium (ISM) properties, and star-formation history.
- Dwarfs are the simplest galactic systems known. However, Local Group dwarfs also show that simple is a relative term. The star formation history of these systems is complex and the trigger for star formation in these galaxies is still an area of active research.

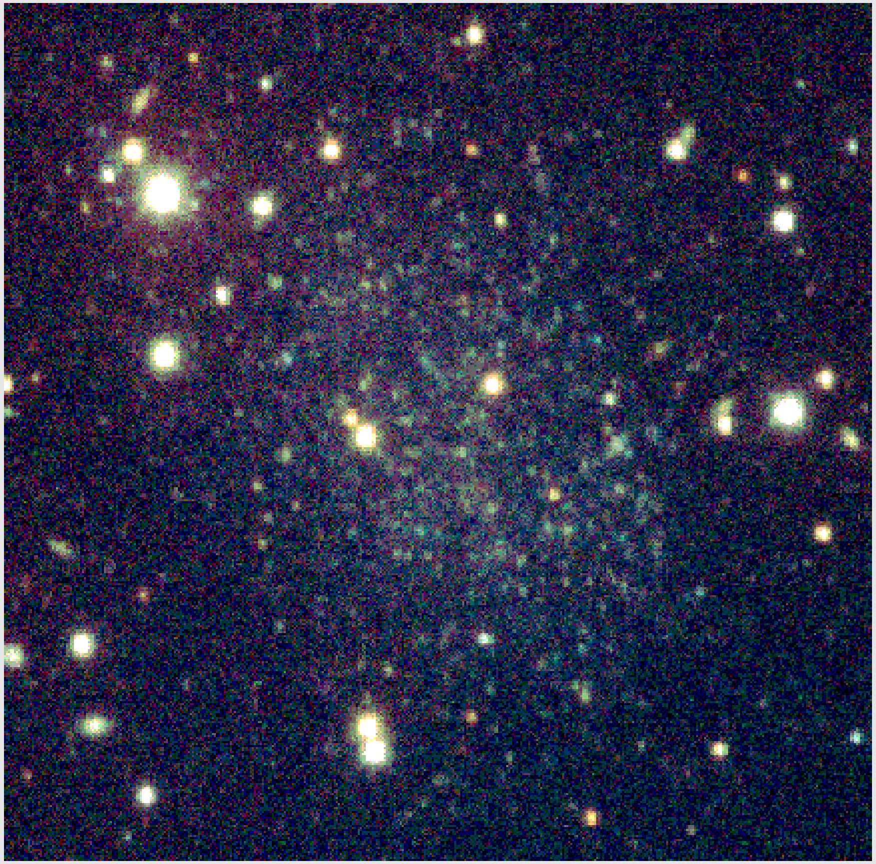


Image NOAO, Antlia dwarf galaxy
D ~ 1.1Mpc and contains only
about 10^6 stars.

Image APOD, AAO
Dwarf galaxy Leo I
D~250 kpc

Image APOD,
Pegasus dSph
D~760 kpc

Image APOD,
NGC 205 Dwarf elliptical near
M31. D~830 kpc

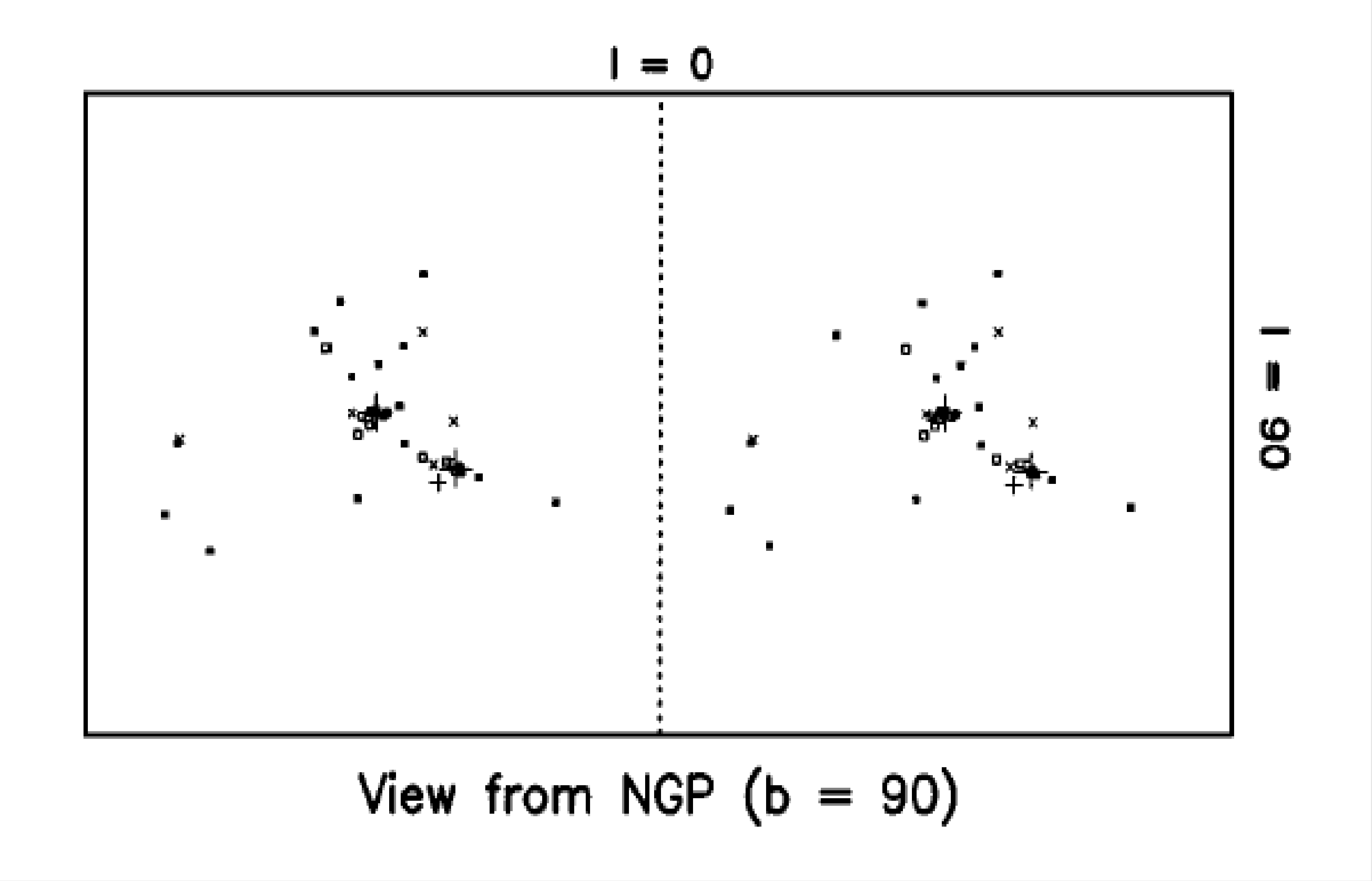
Spatial structure in the local group

With the large number of galaxies in the local group we can start to look at the structure of our group.

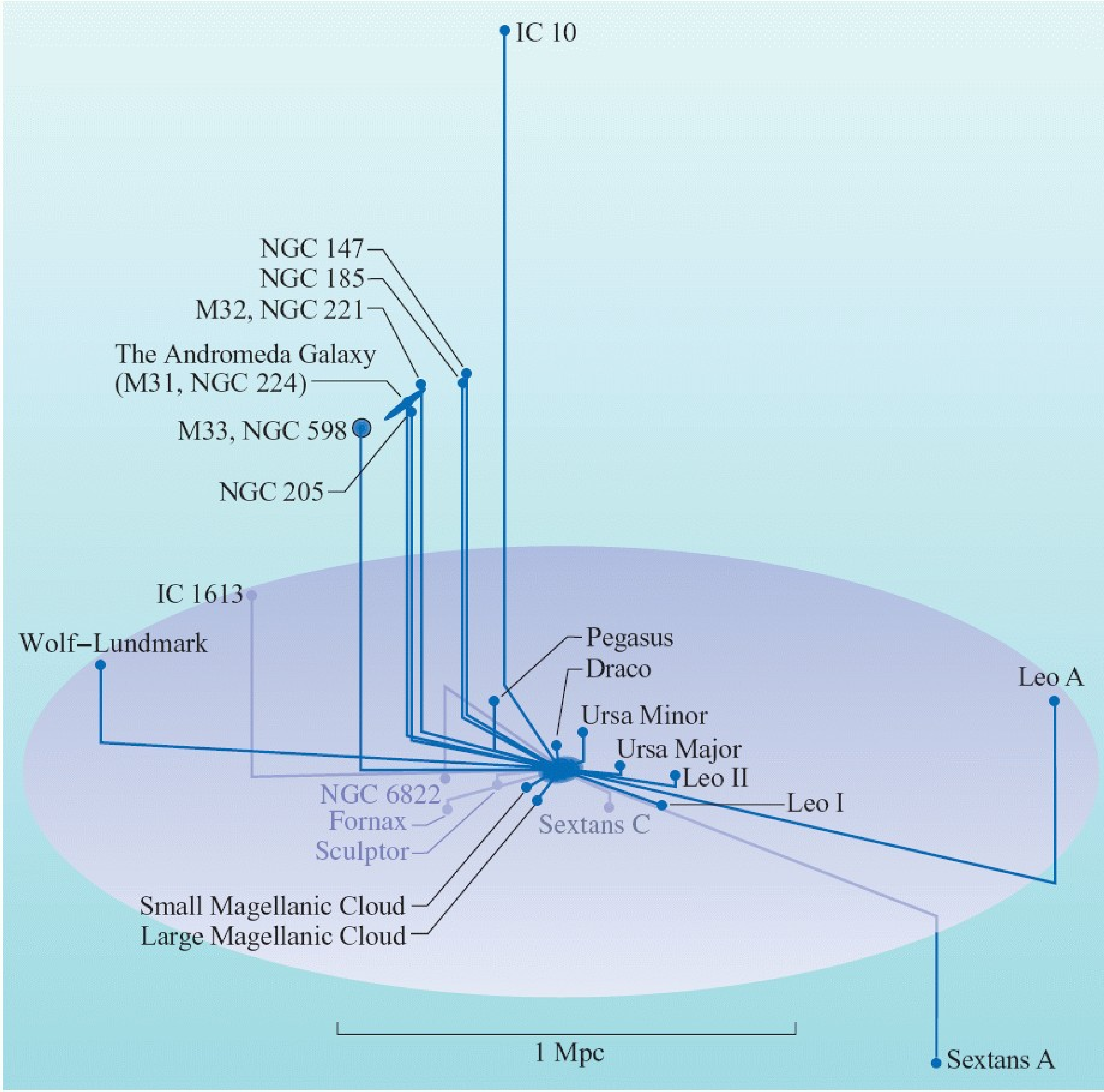
Two conspicuous concentrations of galaxies are around the MW and M31 and consist of a mixture of dIrr and dSph/dE galaxies.

There is a third “cloud” more diffuse than the ones around the MW and M31 and is mostly dIrr.

The fourth group is relatively isolated from the other three groups and contains NGC 3109 (Irr) as its brightest member.



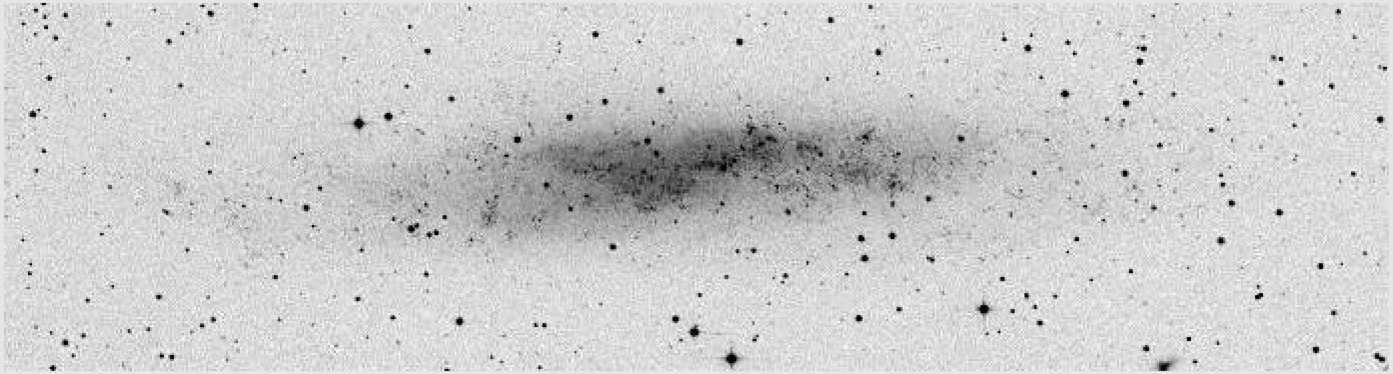
Stereoscopic of the local group (Mateo ARAA 36,435)



IC 10
NGC 147
NGC 185
M32, NGC 221
The Andromeda Galaxy
(M31, NGC 224)
M33, NGC 598
NGC 205
IC 1613
Wolf–Lundmark
Pegasus
Draco
Leo A
Ursa Minor
Ursa Major
Leo II
Leo I
NGC 6822
Fornax
Sculptor
Sextans C
Small Magellanic Cloud
Large Magellanic Cloud
1 Mpc
Sextans A

Optically the dIrr galaxies are dominated by bright OB associations and star forming regions with typical diameters of 200 – 300 pc.

These regions are rarely located at the centers of the system. The dIrr NGC 3109



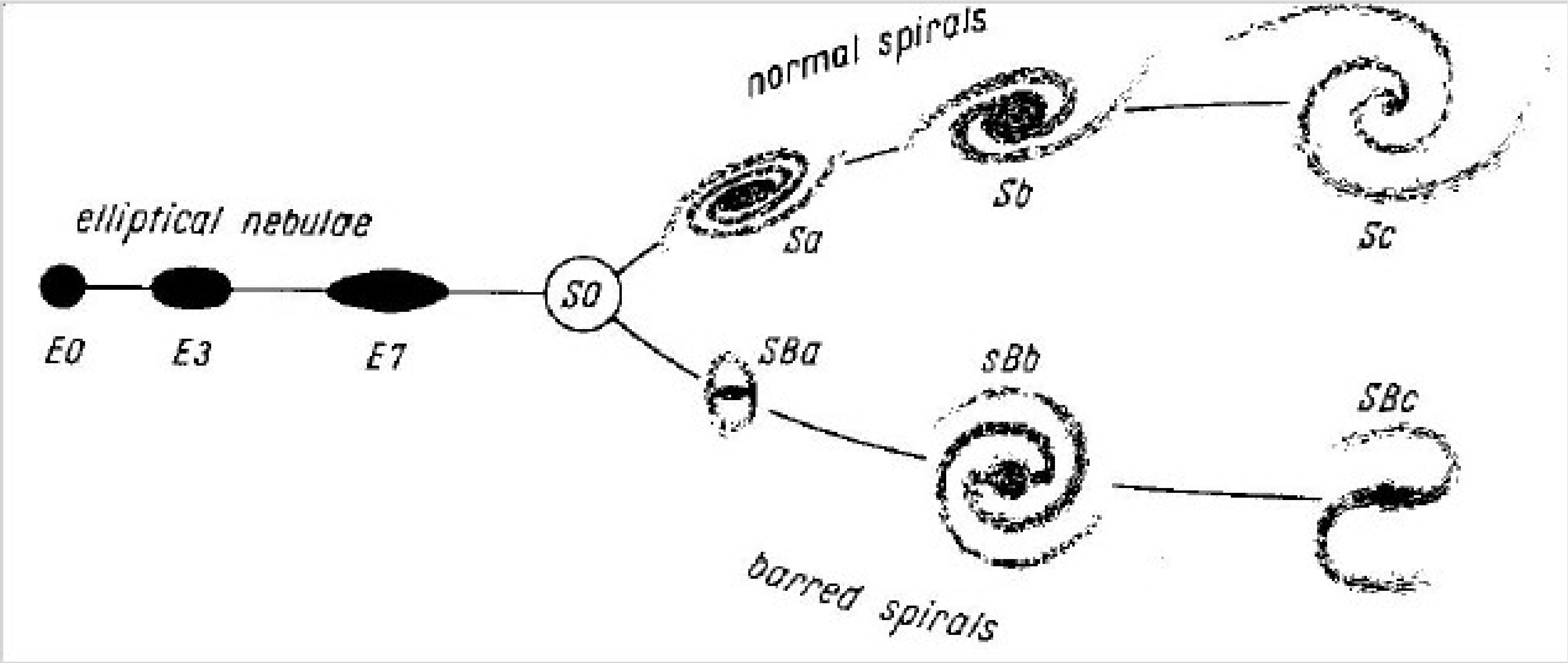
shows evidence of a faint spiral structure (like the LMC) and all these galaxies have a smooth population of older stars underlying the star forming regions and OB associations.

The dE systems are dominated by a smooth spherically symmetric component with star forming regions only seen occasionally. The star forming regions in these systems are much closer (but not coincident) with the nucleus.

- Irr galaxies contain a large amount of HI gas
  - 7% - 50% of the total mass
  - HI gas is mostly in clumps 100 - 300 pc
- HI clumps are often associated with star forming regions
- Dust is prevalent and is also clumped D~10-20pc

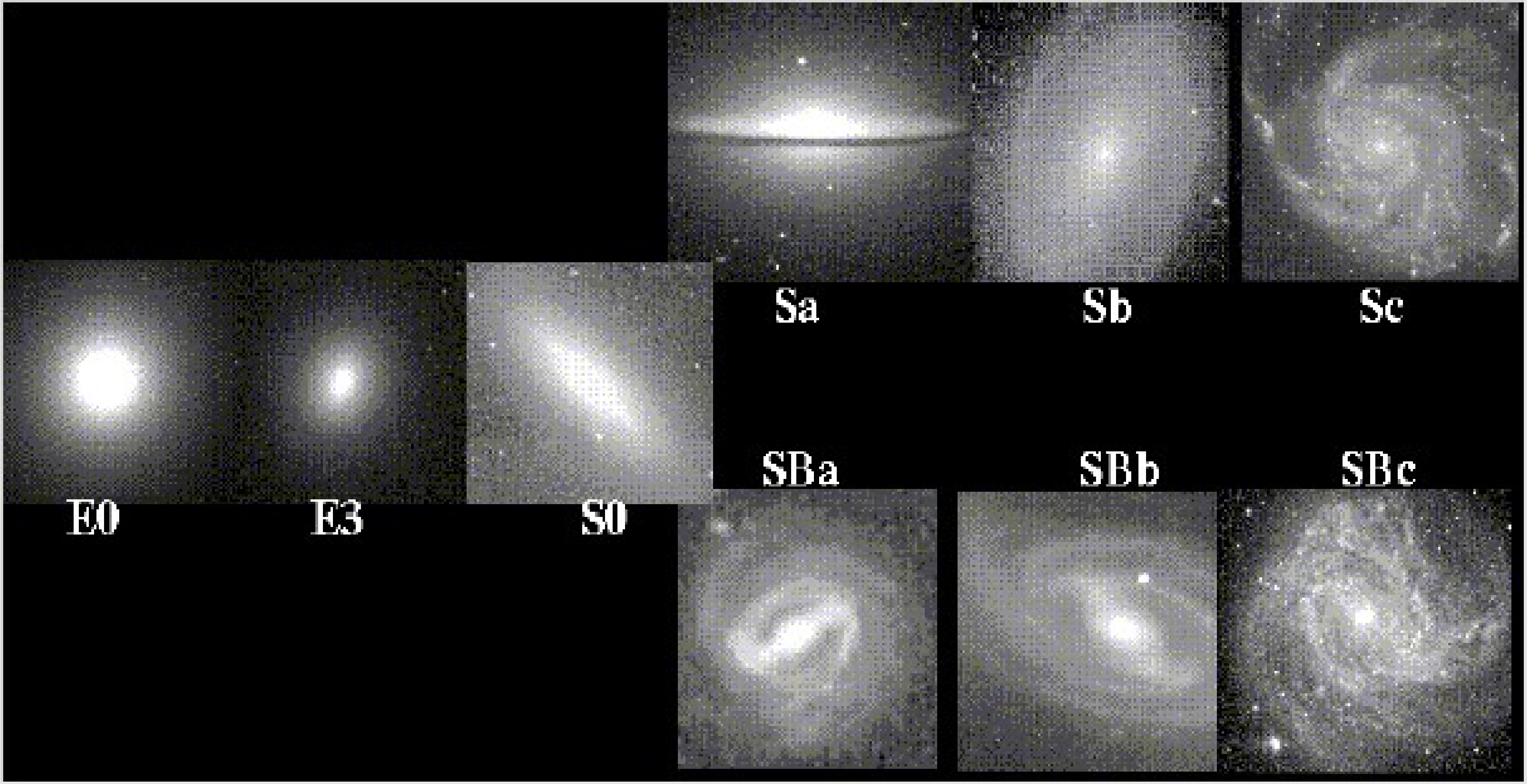
- dE galaxies contain little or no HI gas and most systems only have upper limits.
  - NGC 185 and NGC 205 do have some HI gas
  - 0.05% of the total mass
- HI gas is near the nucleus
- Some dust mostly near the core

Galaxy Classification



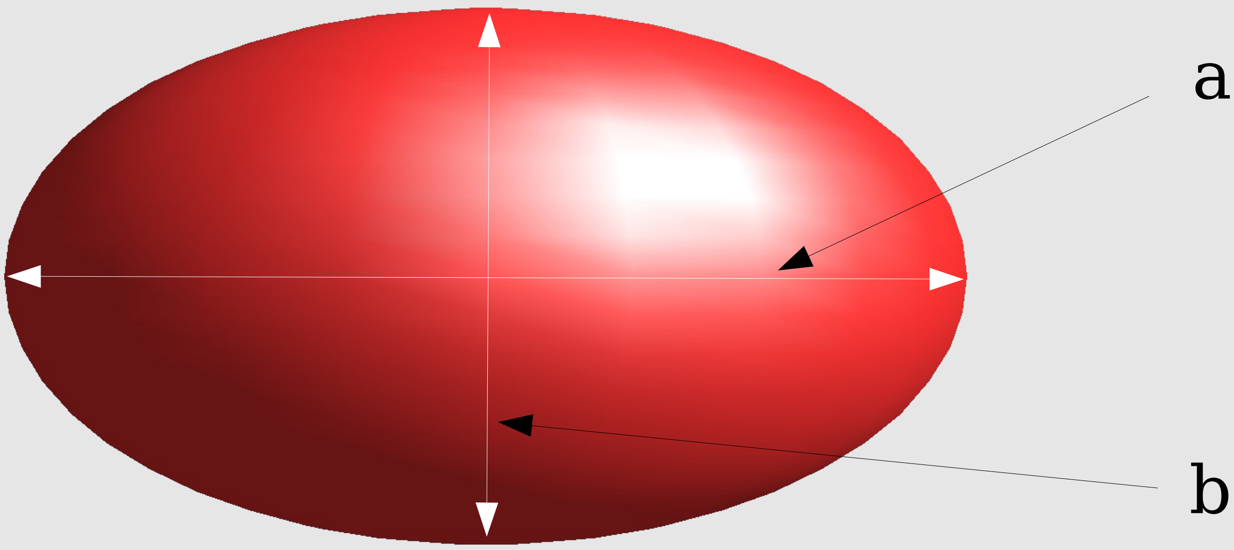
Edwin Hubble (1936) outlined the first widely accepted galaxy classification scheme based on how he thought the different forms evolved. Often called the tuning fork diagram.

Early type --> Late type

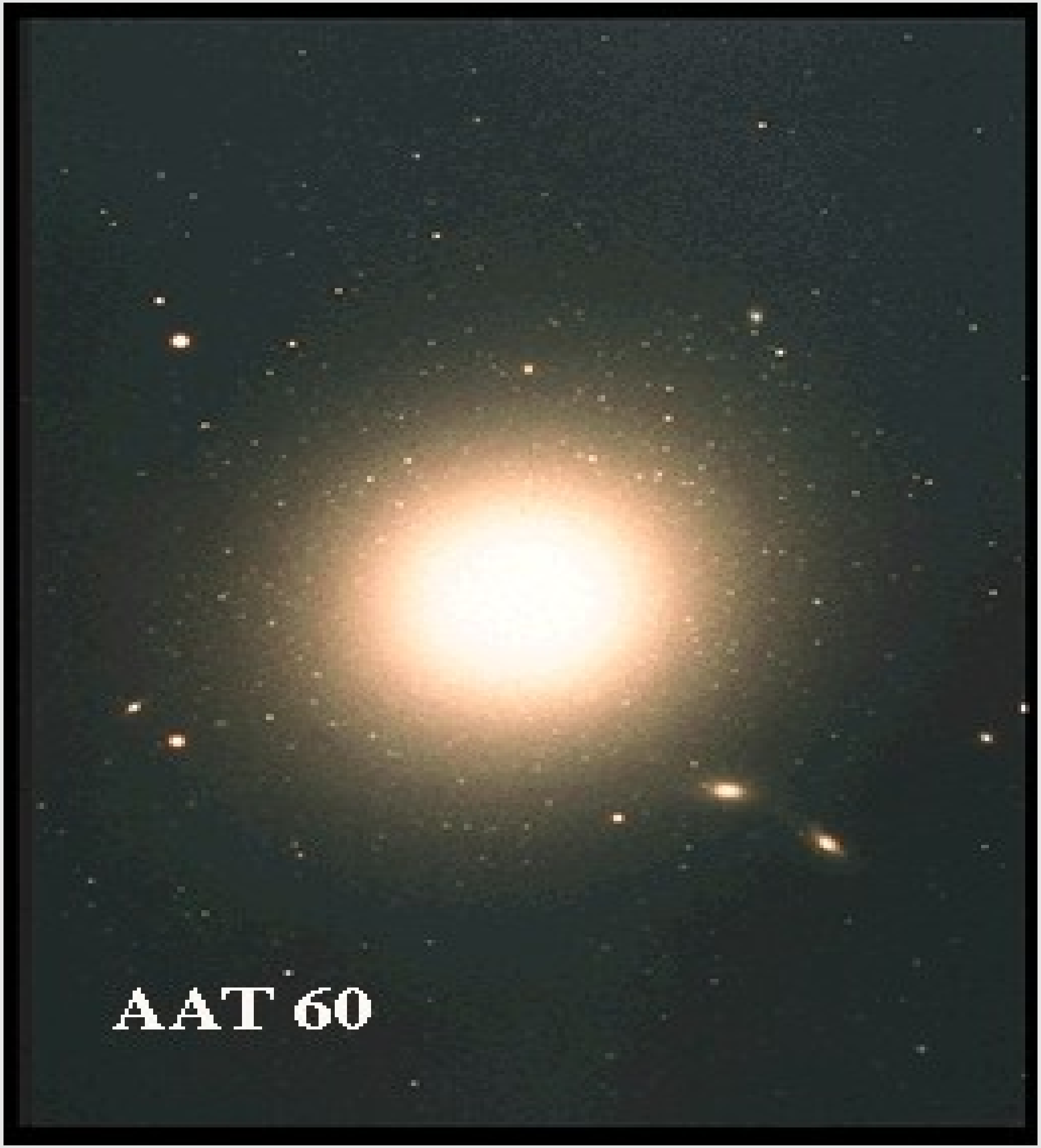


Tuning fork diagram using real galaxies. We now know this is *NOT* an evolutionary sequence.

Elliptical Classification



Define ellipticity as $\epsilon = 1 - b/a$, this is used in their classification, $b/a = 1 - n/10$, to get En classification.



M87 (NGC 4486) E3pec

Spiral galaxies are named for their bright spiral arms, which are prominent due either to bright O and B stars (evidence for recent star formation), and/or to dust lanes.

Define two sequences of spiral galaxies:

Sa -> Sb -> Sc -> Sd in order of decreasing bulge size.

And

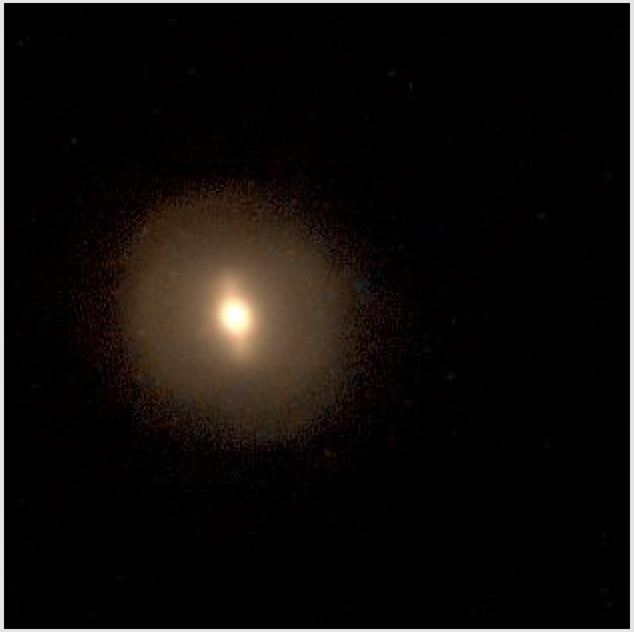
SBa -> SBb -> SBc -> SBd again in order of decreasing bulge size but with a bar in the center.

M101 HST

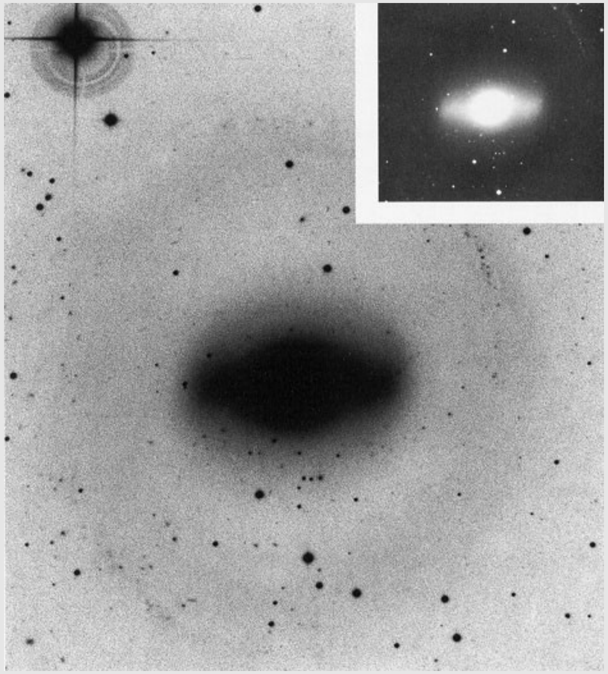
NGC 1365 APOD

Transition class between ellipticals and spirals are the S0 galaxies, also called lenticulars. S0 galaxies have a rotating disk in addition to a central elliptical bulge, but the disk lacks spiral arms or prominent dust lanes.

Lenticulars can also have a central bar, in which case they are labeled SB0.

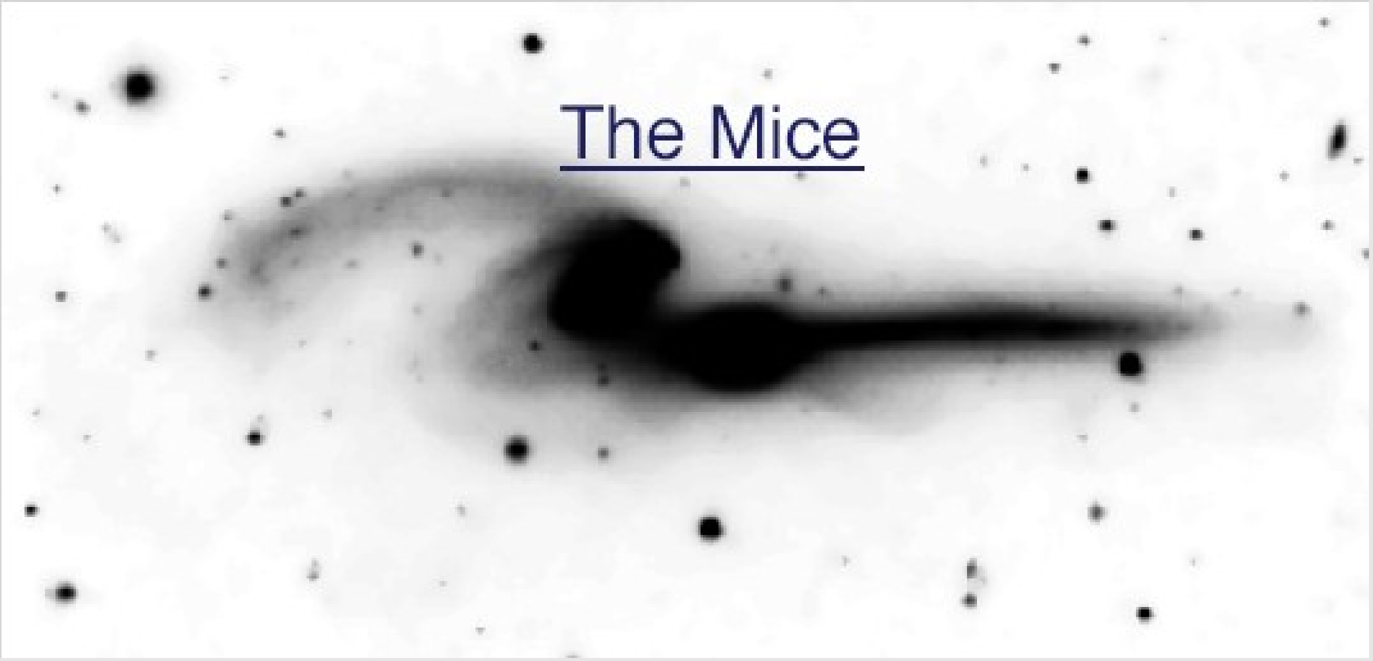


NGC 4477



NGC 1543

Hubble dubbed galaxies that didn't fit into his scheme irregular Today: irregular galaxies are defined as small blue galaxies lacking any organized spiral structure. Other types of galaxy Hubble called irregular are now identified as starburst or interacting galaxies. These have a disturbed appearance due to recent episodes of violent star formation, or close encounters with other galaxies.



Trends within the Hubble Sequence

- E0 --> S0 --> Sb
  - Decreasing bulge to disk ratio
  - Decreasing stellar age
  - Increasing gas content
  - Increasing star formation rate

Problems with Hubble's classification

- Constructed to classify massive galaxies
- Spiral parameters not well defined in the sequence
- Bars are yes/no, observations show that bars form a continuum of strengths
- Works best for isolated systems, in clusters classifications can be difficult

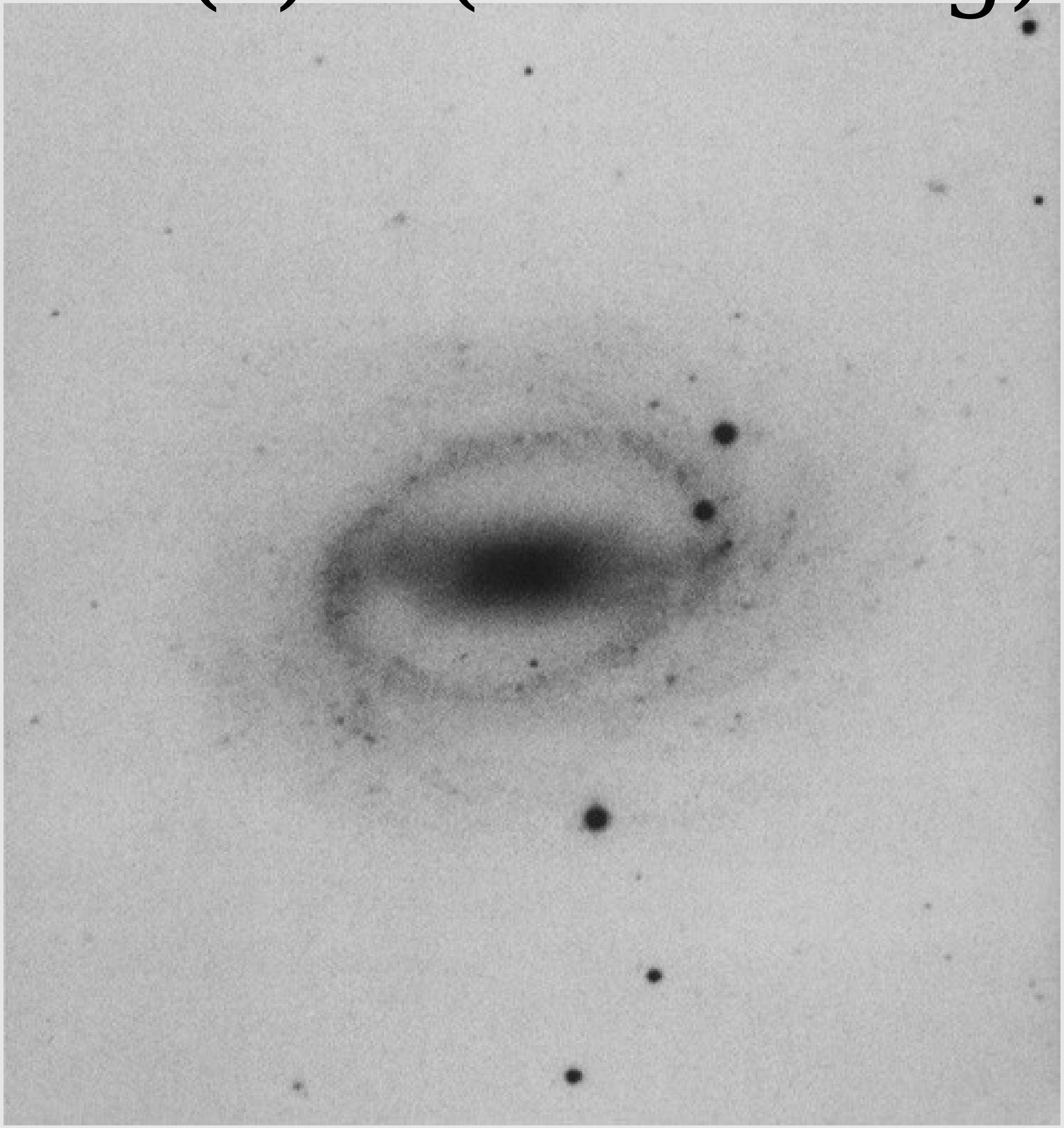
de Vaucouleurs' revision

- Mixed types
  - Sab , Scd, S0/a, E/S0 for intermediate types
  - S no bar, SB strong bar, SAB intermediate bar
- Inner rings
  - Arms in ring (r)
  - Arms out of ring (s)
  - And (rs)

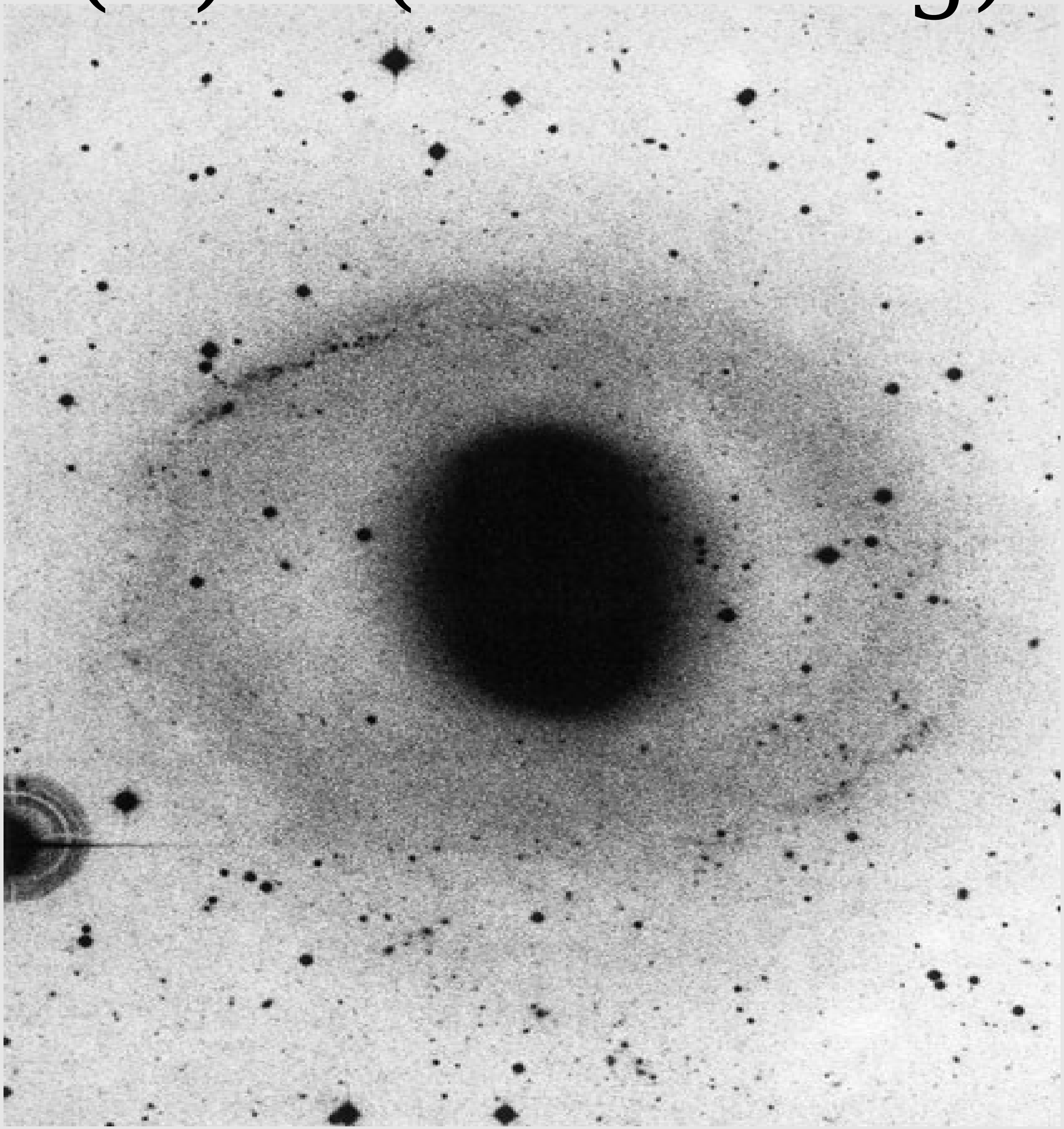
de Vaucouleurs' revision cont.

- Outer ring (R)S
- Extend the Spiral/Irr type
  - Sd (very small bulge)
  - Sdm (intermediate between Sd and Im)
  - Im (Irr class)
  - Sm (Magallanic type spirals)
    - LMC is SB(s)m

IC 5240 example of a SB(r)ab(inner ring)



NGC 1543 example of a (R)SB(Outer ring)



NGC 6783 example of a (R)SB(r)

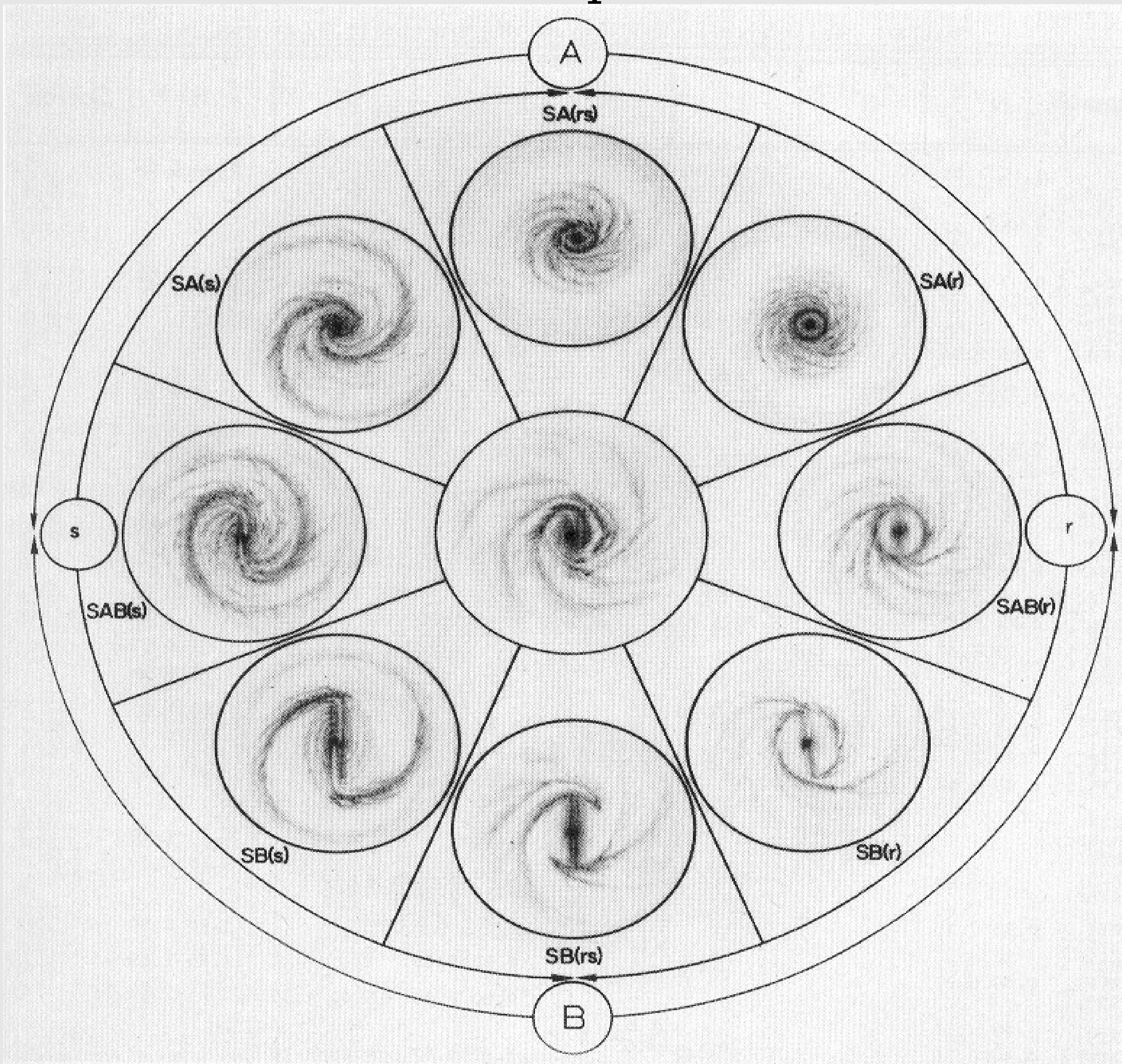
De Vaucouleurs also introduced the T type

E0 -->	S0 -->	Sa -->	Sb -->	Sc -->	Im
-5	-1	1	3	5	10

so that computers could be used with his catalogs (RC1 1964, RC2 1974, RC3 1991)

Pure Spiral

Intermediate

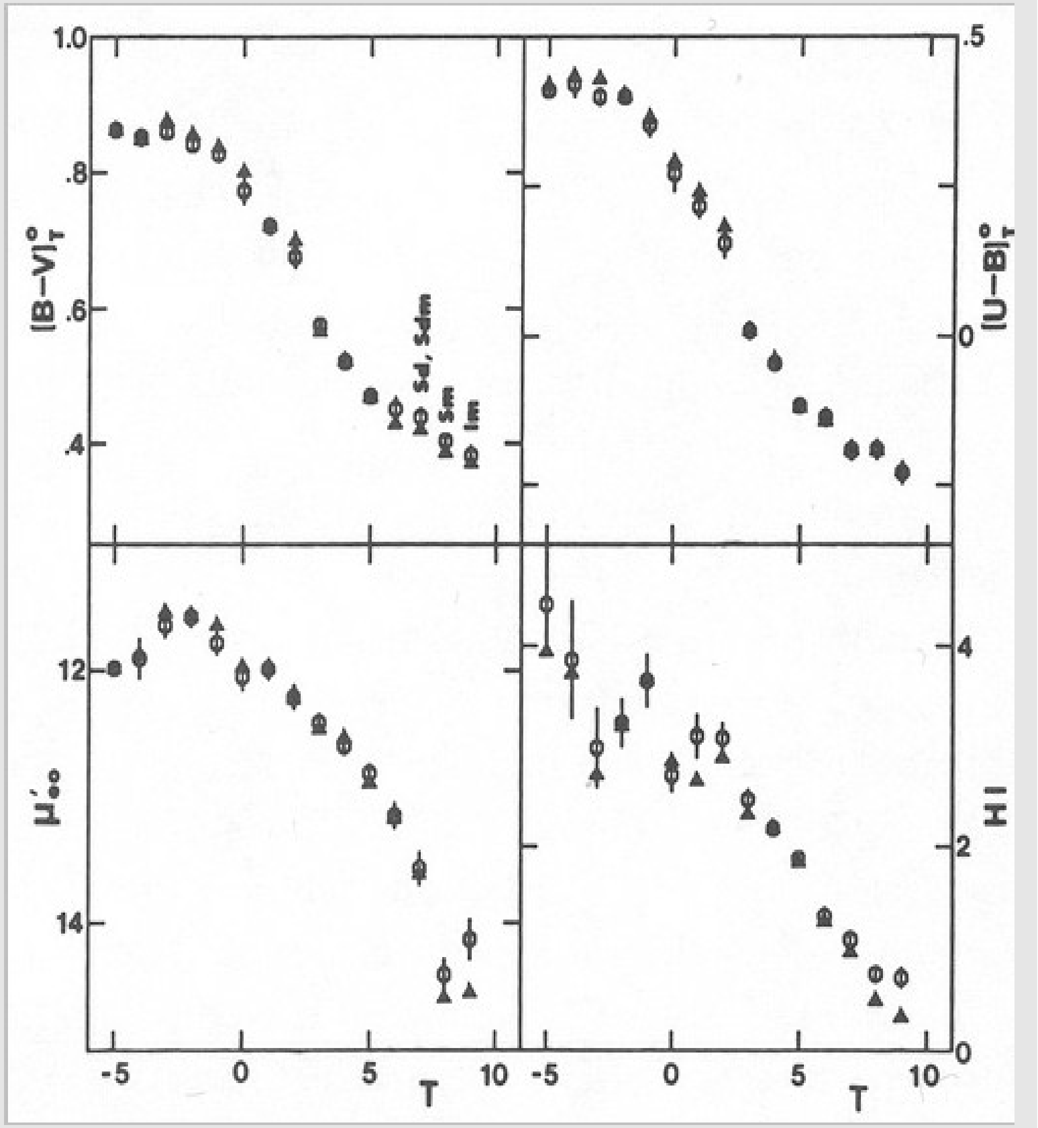


Ring

Bar

Advantages of the new system

- Classes are more continuous
- Can classify up to 97% of all galaxies without special bins
- Describes features that are clues to the dynamics
- In wide use



Limitations of the new system

- E -> Im is not a linear sequence of 1 parameter
- Terms are not universally applicable
  - What do ring or bars mean for ellipticals?
- Visual system
  - Not based of a physical parameter (mass, luminosity etc)
- Parameters are not always independent
  - Rings and bars

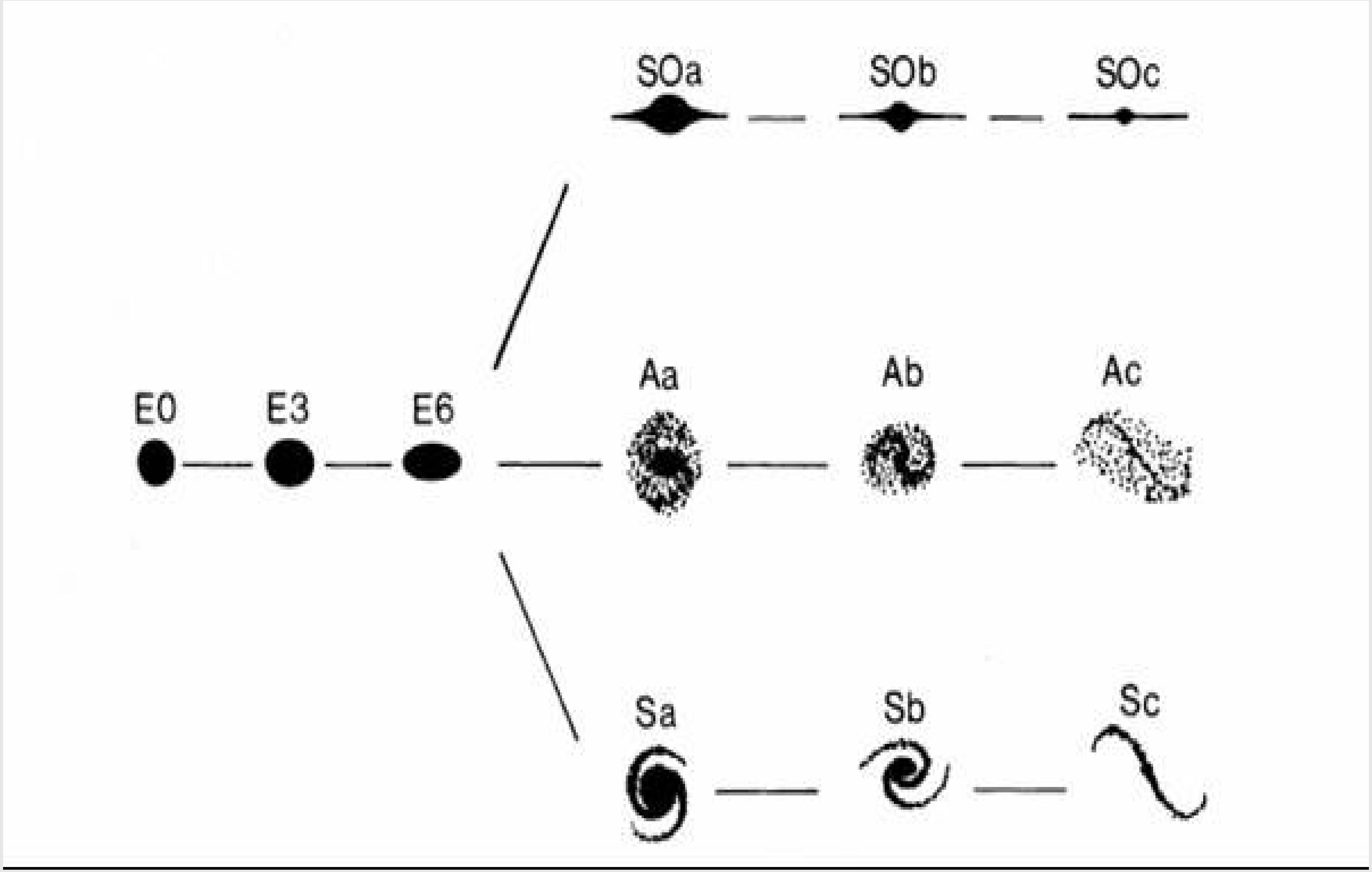
Modifications

- DDO system (Van den Bergh 1960)
  - Added luminosity as a parameter
    - Star formation, gas content, spiral arm "development"
  - Mostly added subclasses to spirals
    - Sc I – well developed arms
    - Sc III – short stubby arms
    - Sc IV – faint spiral structure (LMC)

Modifications cont.

- DDO system (Van den Bergh 1976)
  - Added Anemic as a class
    - Lower gas content than galaxies with similar luminosity
    - Lower star formation rates
    - Spiral arms less well developed

DDO classification of Galaxies



Problems with the DDO system

- Complicated
- Anemic is not necessarily an intrinsic parameter
  - Ram pressure stripping
  - Merger activity

As a result it is not as commonly used as the de Vaucouleurs system